PENNSTATE

RADIATION SCIENCE AND ENGINEERING CENTER

COLLEGE OF ENGINEERING

THIRTY-SEVENTH ANNUAL PROGRESS REPORT

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PREFACE

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Administrative responsibility for the Radiation Science and Engineering Center (RSEC) resides in the Department of Nuclear Engineering in the College of Engineering. Overall responsibility for the reactor license resides with the Senior Vice President for Research and Dean of the Graduate School. The reactor and associated laboratories are available to all Penn State colleges for education and research programs. In addition, the facility is made available to assist other educational institutions, government agencies and industries having common and compatible needs and objectives, providing services that are essential in meeting research, development, education and training needs.

The Thirty-seventh Annual Progress Report (July 1991 through June 1992) of the operation of The Pennsylvania State University Radiation Science and Engineering Center is submitted in accordance with the requirements of Contract DE-AC07-76ID01570 between the United States Department of Energy and EG&G Idaho, Incorporated, and their Subcontract C88-101857 with The Pennsylvania State University. This report also provides the University administration with a summary of the utilization of the facility for the past year.

Numerous individuals are to be recognized and thanked for their contributions to this report, especially Terry Flinchbaugh who edited the report. The contribution of Lisa Large for its typing is recognized and appreciated. Special thanks are extended to those responsible for the individual sections as listed in the Table of Contents and to the individual facility users whose research summaries are compiled in Section XI.

INTRODUCTION

I. INTRODUCTION

A celebration at the Radiation Science and Engineering Center (RSEC) on May 29, 1992, marked what the RSEC stands for; past, present and future. The following are highlights of that event:

* The reactor was declared a nuclear historic landmark with the citation "On July 8, 1955, (the Penn State Breazeale Reactor) received the first research reactor license issued by the U.S. Atomic Energy Commission, thereby launching a tradition of education and research in nuclear technology."

  Penn State President, Dr. Joab Thomas, accepted the landmark award from American Nuclear Society President, Dr. Robert Long.

* Dr. Eric Walker, former Penn State President and Dean of the College of Engineering when the decision was made to build the reactor, spoke on the roots of the nuclear program at Penn State.

* The new reactor control and safety system which the RSEC staff procured, licensed and installed was dedicated. David Helwig, Vice President of Nuclear Engineering and Services, represented the major donor of the control system, the Philadelphia Electric Company.

* Dr. Forrest Remick, commissioner of the U.S. Nuclear Regulatory Commission and former Director of the Breazeale Reactor, spoke on the future of nuclear technology.

* The new control system places the Breazeale Reactor among the best facilities in the nation for performing research and educating students in reactor control theory.

* The campus and community were invited to an open house in conjunction with the ceremony.

Significant factors of RSEC operation during the year include the following:

* Major physical plant improvements included renovating the control room, replacing the majority of the control and alarm cables throughout the facility, upgrading control and alarm systems and functions, upgrading the public address system and completing the indoor and outdoor painting.

* Reactor radiation monitoring instrumentation and gamma spectroscopy equipment was purchased through a Department of Energy grant. A similar grant for the next DOE fiscal year was approved at $44,036 for spare parts for the control system and a smart alarm system.

* New Macintosh II computers were procured and effectively implemented in the NucE 451 Reactor Physics laboratory course. A student computer room with laser printing capability was set up for times the Macs are not in use in the laboratory.

* The Low Level Monitoring Laboratory, following a year of complete personnel turnover, rose to the challenge of successfully testing drinking water samples required every fourth year by the Pennsylvania Department of Environmental Resources.

* The Reactor Operation's staff began a detailed analysis of the energy spectrum of the neutron flux in locations where semiconductors are irradiated to take leadership in compliance with new ASTM procedures.

* Two retirements eliminated 70 years of cumulative experience, bringing the experience level of the staff to a new low, creating a substantial training workload

Along with all these enhancements in facilities, programs and operations, the staff assisted researchers, instructors and students in many routine experiments, laboratory classes and service irradiations. Pre-college education was also prominent in RSEC programming, as evidenced by the many tour groups, field trips/work shops and teaching sessions conducted by the staff. The RSEC staff is to be commended for working diligently during the past year in accomplishing a new threshold of productivity and professional development.

REACTOR OPERATIONS

III. REACTOR OPERATIONS

Research reactor operation began at Penn State in 1955. In December of 1965 the original core, which operated at a maximum power level of 200 KW, was replaced by a more advanced TRIGA core, capable of operation at 1000 KW. The present core may also be operated in a pulse fashion in which the power level is suddenly increased from less than 1 KW to up to 2000 KW for short (milliseconds) periods of time. TRIGA stands for Training, Research, Isotope Production, built by General Atomic Company.

Utilization of the PSBR falls into three major categories:

Educational utilization is primarily in the form of laboratory classes conducted for graduate and undergraduate degree candidates and numerous high school science groups. These classes will vary from the irradiation and analysis of a sample to the calibration of a reactor control rod.

Research accounts for a large portion of reactor time which involves Radionuclear Applications, Neutron Radiography, a myriad of research programs by faculty and graduate students throughout the University and various applications by the industrial sector.

Training programs for Reactor Operators and Reactor Supervisors are offered and can be tailored to meet the needs of the participants. Individuals taking part in these programs fall into such categories as PSBR reactor staff and power plant operating personnel.

The PSBR core, containing about 7.5 pounds of Uranium-235, in a non-weapons form, is operated at a depth of approximately 18 feet in a pool of demineralized water. The water provides the needed shielding and cooling for the operation of the reactor. It is relatively simple to expose a sample by merely positioning it in the vicinity of the reactor at a point where it will receive the desired radiation dose. A variety of fixtures and jigs are available for such positioning. Various containers and irradiation tubes can be used to keep samples dry. Three pneumatic transfer systems with different neutron levels offer additional possibilities.

In normal steady state operation at 1000 kilowatts, the thermal neutron flux available varies from approximately 1×10^{13} n/cm^2/sec at the edge of the core to approximately 3×10^{13} n/cm^2/sec in the central region of the core.

When using the pulse mode of operation, the peak flux for a maximum pulse is approximately 6×10^{16} n/cm^2/sec with a pulse width of 15 msec at 1/2 maximum.

Support facilities include a machine shop, electronic shop, laboratory space and fume hoods.

STATISTICAL ANALYSIS

Tables 2 and 3 list Reactor Operation Data and Reactor Utilization Data-Shift Averages, respectively, for the past three years. In table 2, the Critical time is a summation of the hours the reactor was operating at some power level. The Subcritical time is the total hours that the reactor key and console instrumentation were on and under observation, less the Critical time. Subcritical time reflects experiment set-up time and time spent approaching reactor criticality. Fuel movement hours reflect the fact that there were minimal fuel movements made this year.

The Number of Pulses reflects demands of undergraduate labs, researchers and reactor operator training groups. Square waves are used primarily for demonstration purposes for public groups touring the facility, researchers and reactor operator training programs.

The number of Scrams Planned as Part of Experiments reflects experimenter needs. The scrams from Personnel Action were a result of operator error. The unplanned scrams resulting from Abnormal System Operation were due to electrical failure and system operational problems. It should be pointed out that a scram shuts down the reactor before a safety limit is reached.

Table 3, Part A, Reactor Usage, indicates Hours Critical and Hours Subcritical, and also Hours Shutdown such as for instruction or experimental setup. Occasionally a component failure prohibits reactor operation. The necessary repair time is included in Reactor Usage as Reactor Not Available to reflect total reactor utilization on a shift basis.

Part B gives a breakdown of the Type of Usage in Hours. The Nuclear Engineering Department and/or the Reactor Facility receives compensation for Industrial Research and Service, and for Industrial Training Programs. University Research and Service includes both funded and non-funded research, for Penn State and other universities. The Instruction and Training category includes all formal university classes involving the reactor, experiments for other university and high school groups, demonstrations for tour groups and in-house reactor operator training.

Part C statistics, Users/Experimenters, reflect the number of users, samples and experimenters per shift. Part D shows the number of eight hour shifts for each year.

INSPECTIONS AND AUDITS

During October of 1991, Michael J. Slobodien, Radiological Controls Director, and Robert J. Barrett Plant Operations Manager, both of GPU Nuclear Corporation conducted an audit of the PSBR. This fulfilled a requirement of the Penn State Reactor Safeguards Committee charter as described in the PSBR Technical Specifications. The reactor staff has implemented changes suggested by that report, all of which exceed NRC requirements.

During November of 1991, a Nuclear Regulatory Commission (NRC) routine inspection was conducted of activities authorized by the materials license 37-00185-05 for the Cobalt-60 facility. A violation (the handling tool for the Cobalt-60 sources was not kept locked) was cited. The handling tool referred to in the license application dated April 30, 1985 is no longer in use. The current source handling tool requires assembly of several components by a person knowledgeable about its use. The requirement to lock the tool was deleted from the license renewal submission of May 1991, which was still under NRC review at the time of the inspection. The critical component of the handling tool is now locked.

During November of 1991, a NRC routine inspection was conducted of the emergency preparedness program and security area key control. No safety concerns or violations were observed.

During June of 1992, a NRC routine inspection was conducted of activities authorized by the special nuclear materials license SNM-95. Also, compliance to the physical security plan for the PSBR was examined. No items of non-compliance were identified.

TABLE 2

Reactor Operation Data
July 1, 1989 - June 30, 1992

		89-90	90-91	91-92
A.	Hours of Reactor Operation			
	1. Critical	507	521	431
	2. Subcritical	305	334	541
	3. Fuel Movement	0	5	37
B.	Number of Pulses	97	111	90
C.	Number of Square Waves	70	74	68
D.	Energy Release (MWH)	331	318	210
E.	Grams U-235 Consumed	17	16	11
F.	Scrams			
	1. Planned as Part of Experiments	23	36	24
	2. Unplanned - Resulting From			
	a) Personnel Action	4	5	2
	b) Abnormal System Operation	3	3	7

TABLE 3

Reactor Utilization Data
Shift Averages
July 1, 1989 - June 30, 1992

		89-90	90-91	91-92
A.	Reactor Usage			
	1. Hours Critical	2.1	2.1	1.7
	2. Hours Subcritical	1.3	1.3	2.1
	3. Hours Shutdown	1.6	1.9	1.7
	4. Reactor Not Available	0.0	0.0	0.7
	TOTAL HOURS PER SHIFT	5.0	5.3	6.3
B.	Type of Usage - Hours			
	1. Industrial Research and Service	1.1	0.8	0.8
	2. University Research and Service	1.8	2.1	1.5
	3. Instruction and Training	0.9	1.2	1.4
	4. Industrial Training Programs	0.1	0.1	0.0
	5. Calibration and Maintenance	1.2	1.1	2.4
	6. Fuel Handling	0.0	0.0	0.1
C.	Users/Experiments			
	1. Number of Users	2.4	2.4	2.8
	2. Pneumatic Transfer Samples	1.3	0.5	0.7
	3. Total Number of Samples	3.6	2.5	2.4
	4. Sample Hours	2.6	2.2	1.5
D.	Number of 8 Hour Shifts	240	247	255

PERSONNEL

II. PERSONNEL

Doug Vonada retired from his electronic designer position on July 14, 1991 after 35 years of service. Dale Raupach retired from his reactor supervisor/reactor utilization specialist position on December 31, 1991 after 34 years of service. Dale has continued to work in a wage payroll position during the transition period until his duties can be assumed by new staff.

Thierry Daubenspeck was hired on February 12, 1992 as reactor supervisor/reactor utilization specialist. Thierry had been employed at the LLRML in a full-time wage payroll position.

Sue Ripka resigned as head secretary in July of 1991 and was replaced by Pam Stauffer in August of 1991. Kim Conlin resigned as a wage payroll secretary in August of 1991. Tracy Williams worked as a wage payroll secretary from August of 1991 to March of 1992. Arlene Stewart was hired as a wage payroll secretary in January of 1992.

Both members of the technical service staff received promotions effective July 1, 1991. Jeff Armstrong's position change was from maintenance worker to mechanic-experimental and maintenance. Ron Eaken changed from experimental and maintenance mechanic to machinist A.

Maurice Peagler was hired into a full time wage payroll position in the LLRML on March 9, 1992. Part-time LLRML wage payroll and work-study help during the year was provided by Chris Burelli, Brett Kellerman and Joy Moncil.

Bryan Vergato was hired as a reactor operator intern on October 14, 1991.

Ken Sahadewan was in a full-time reactor wage payroll position until January 31, 1992. Other reactor part-time wage payroll and work-study help during the year was provided by John DeMarco, Dave Esh and Joy Moncil.

On January 1, 1992, the following change occurred in the membership of the Penn State Reactor Safeguards Committee (PSRSC). Asok Ray (Associate Professor of Mechanical Engineering) resigned from the committee after serving a three year term. His replacement was John Mahaffy (Assistant Professor and Research Associate at ARL).

The PSRSC Subcommittee for Control System Installation consisted of committee member Asok Ray, Edward Kenney (Professor of Nuclear Engineering - retired) and Warren Witzig (Professor and Department Head of Nuclear Engineering - retired). The subcommittee reported to PSRSC chairman, Gordon Robinson.

TABLE I

Personnel

Faculty and Staff	Title
H. M. Boyle	Supervisor, Low-Level Radiation Monitoring Lab
* P. G. Boyle	Reactor Supervisor/Nuclear Education Specialist
**M. E. Bryan	Electronic Designer/Reactor Supervisor
G. L. Catchen	Associate Professor
T. Daubenspeck	Reactor Supervisor/Reactor Utilization Specialist
**C. C. Davison	Reactor Supervisor/Nuclear Education Specialist
**T. L. Flinchbaugh	Operations and Training Manager
J. E. Goodfellow	Environmental Analyst
R. Gould	Project Assistant
**E. Hannold	Reactor Operator Intern
**D. E. Hughes	Senior Research Assistant/Manager of Engineering Services
W. A. Jester	Professor
T. S. Narehood	Administrative Assistant
**D. C. Raupach (retired)	Reactor Supervisor/Reactor Utilization Specialist
* K. E. Rudy	Operational Support Services Supervisor
**E. J. Sipos	Reactor Operator Intern
**B. D. Vergato	Reactor Operator Intern
* D. S. Vonada (retired)	Electronic Designer
**M. H. Voth	Associate Professor/Director

* Licensed Operator
**Licensed Senior Operator

Clerical Staff	
K. M. Conlin (resigned)	Secretary - wage payroll
L. D. Large	Secretary and Receptionist
S. K. Ripka (resigned)	Facility Secretary
P. J. Stauffer	Facility Secretary
A. Z. Stewart	Secretary - wage payroll
T. J. Williams (resigned)	Secretary - wage payroll

Technical Service Staff	
J. E. Armstrong	Mechanic-Experimental and Maintenance
R. L. Eaken	Machininst A

Student Work-Study or Wage Payroll

C. Burelli	B. Kellerman
T. Daubenspeck	J. Moncil
J. DeMarco	K. Sahadewan
D. Esh	

Penn State Reactor Safeguards Committee

W. S. Diethorn	Professor, Nuclear Engineering, Penn State (retired)
E. W. Figard	Supervisor of Maintenance, Pennsylvania Power and Light Susquehanna Steam Electric Station
R. W. Granlund	Health Physicist, Intercollege Research Programs and Facilities, Penn State
D. E. Hughes	Senior Research Assistant, Penn State Radiation Science and Engineering Center
P. Loftus	Manager, Product Licensing, Westinghouse
J. H. Mahaffy	Assistant Professor and Research Associate, ARL, Penn State
*A. Ray	Associate Professor, Mechanical Engineering, Penn State
G. E. Robinson	Chairman, Associate Professor, Nuclear Engineering, Penn State
M. J. Slobodien	Radiological Controls Director, General Public Utilities
P. E. Sokol	Associate Professor, Physics, Penn State
M. H. Voth	Ex officio, Director, Penn State Radiation Science and Engineering Center

*Served through 1 January 1992

Penn State Reactor Safeguards Subcommittee for Control System Installation

A. Ray	Associate Professor, Mechanical Engineering, Penn State
E. S. Kenney	Professor, Nuclear Engineering, Penn State (retired)
W. F. Witzig	Professor and Department Head, Nuclear Engineering, Penn State (retired)

Penn State Users Advisory Committee

S. Carpenter	National Institute of Science and Technology (NIST)
J. M. Cimbala	Associate Professor, Mechanical Engineering, Penn State
E. H. Klevans	Department Head and Professor, Nuclear Engineering, Penn State
W. A. Jester	Professor, Nuclear Engineering, Penn State
A. A. Heim	Director, Industrial Research Office, Penn State
R. O. Mumma	Professor, Entomology, Penn State
L. J. Pilione	Professor, Physics, Penn State
F. H. Ruddy	Senior Scientist, Westinghouse
A. W. Rose	Professor, Geochemistry, Penn State
J. R. Thorpe	Simulation Management Director, General Public Utilities
M. H. Voth	Ex officio, Director, Penn State Radiation Science and Engineering Center

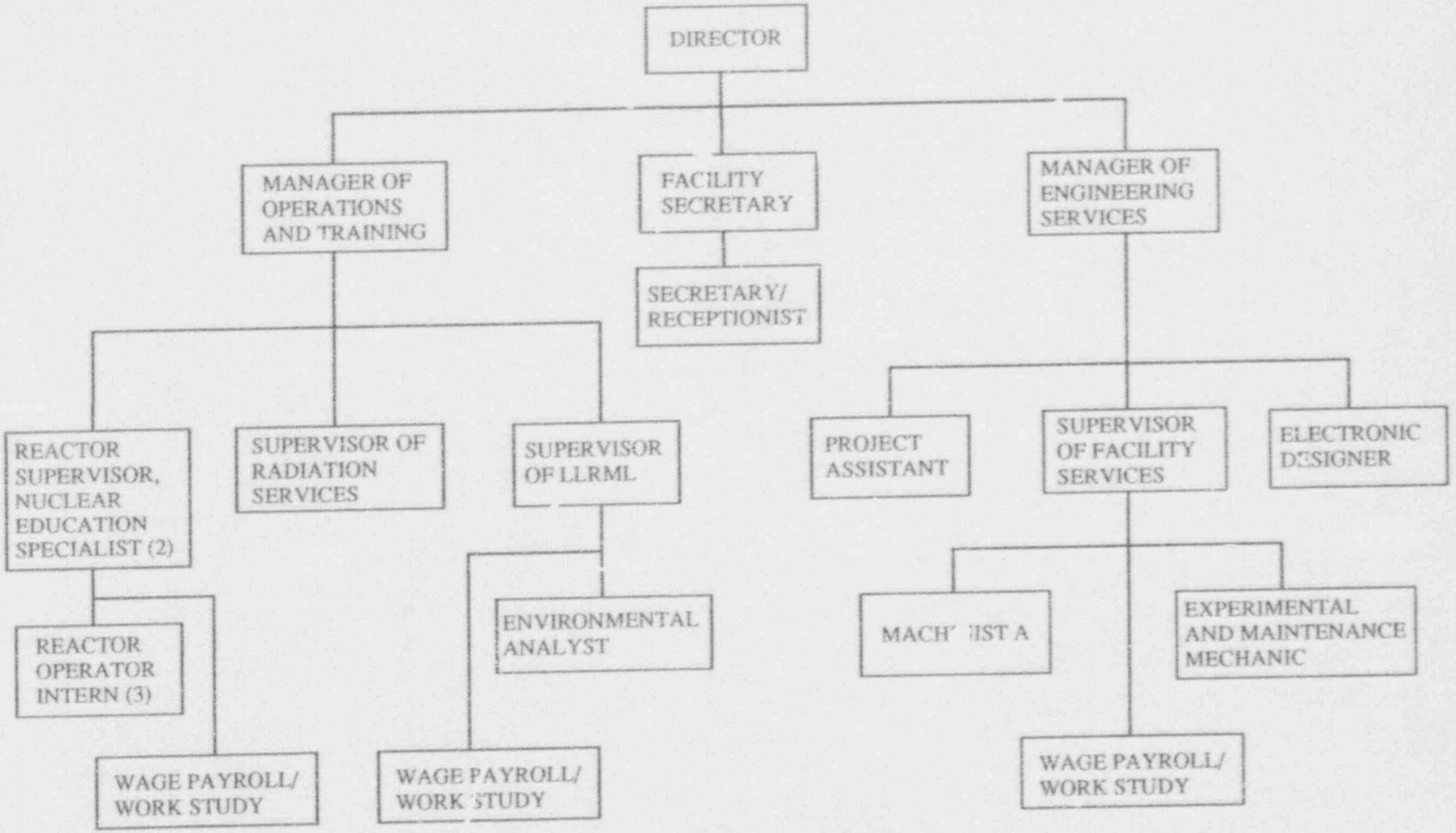

FIGURE 1 RSEC Organization Chart

NEUTRON BEAM LABORATORY

VI. NEUTRON BEAM LABORATORY

The Neutron Beam Laboratory (NBL) is one of the experimental facilities that is a part of the RSEC. A well collimated beam of neutrons, thermalized by a D_2O thermal column, is passed into the NBL for use in non-destructive testing and evaluation. Work now being done utilizes a Real Time Neutron Image Intensifier, by Precise Optics, Inc., for real time radiography. The beam is also being used for static neutron radiography and neutron attenuation studies, and flash radiography utilizing pulsing. There is also equipment available to digitize the real time radiography images for image processing.

The NBL was established partially with funds from the U.S. Department of Energy with matching funds from the University. The Neutron Beam Laboratory at The Pennsylvania State University RSEC was established to:

1. Educate students and the public on an important use of neutrons from a research reactor,

2. Establish a demonstration center, "Neutrons in Action," to show that their use is beneficial to mankind, and

3. Expand the use of neutron radiography in research, both as a tool for improving the development of U.S. industrial products and to develop new information in other fields of science and engineering.

Bettis Atomic Power Laboratory purchased time to utilize the neutron beam laboratory to evaluate two phase flow during the past year and the project continues. We continue to have funded service work utilizing the beam to measure neutron attenuation of boraflex materials that have seen service in fuel storage pools.

GAMMA IRRADIATION FACILITY

IV. GAMMA IRRADIATION FACILITY

The University, in March of 1965, purchased 23,600 curies of Cobalt-60 in the form of stainless steel clad source rods to provide a pure source of gamma rays. In November of 1971, the University obtained from the Natick Laboratories, 63,537 curies of Cobalt-60 in the form of aluminum clad source rods. These source rods have decayed through several half-lives, leaving a July 1, 1992 approximate total of 4,800 curies.

In this facility, the sources are stored and used in a pool 16 feet by 10 feet, filled with 16 feet of demineralized water. The water provides a shield which is readily worked through and allows great flexibility in using the sources. Due to the number of rods and size of the pool, it is possible to set up several irradiators at a time to vary the size of the sample that can be irradiated, or vary the dose rate. Experiments in a dry environment are possible by use of either a vertical tube or by a diving bell type apparatus.

The Cobalt-60 facility is designed with a large amount of working space around the pool and has two laboratory rooms equipped with work benches and the usual utilities.

Maximum exposure rates of 180 KR/Hr in a 3" ID tube and 104 KR/Hr in a 6" ID tube are available as of July 1, 1992.

Efforts continue to obtain 12,000 curies of Cobalt-60 in the form of 15 source rods from Battelle National Labs. The sources will be donated to Penn State. One of the current storage casks was modified and a third storage cask was built to accommodate dry storage of the additional sources.

Table 4 compares the past three years' utilization of the Cobalt-60 facility in terms of time, numbers and daily averages.

TABLE 4

Cobalt-60 Utilization Data
July 1, 1989 - June 30, 1992

		89-90	90-91	91-92
A.	Time Involved (Hours)			
	1. Set-Up Time	358	215	185
	2. Total Sample Hours	11,692	14,277	12,549
B.	Numbers Involved			
	1. Samples Run	1,433	756	740
	2. Different Experimenters	23	30	35
	3. Configurations Used	3	3	3
C.	Per Day Averages			
	1. Experimenters	1.95	0.8	0.6
	2. Samples	5.76	3.04	2.97

EDUCATION AND TRAINING

V. EDUCATION AND TRAINING

During the past year, the Penn State RSEC was used for a variety of educational services; in-house training , formal laboratory courses and many continuing education programs and tours.

In-house reactor operator requalification consisted of an oral examination on abnormal and emergency procedures given by K. E. Rudy, an operating test given by T. L. Flinchbaugh and a written exam given by D. E. Hughes.

Licensed reactor operator intern Eric Sipos was granted a NRC senior operator license in December of 1991. Bryan Vergato joined the staff in October of 1991 as an intern and was granted a NRC senior operator license in May of 1992. Staff member Patrick Boyle, a licensed reactor operator, was denied his senior operator license by the NRC in May of 1992.

The sixth session of the Pennsylvania Governor's School for Agricultural Sciences was held at Penn State's University Park campus during the summer of 1991. Sixty-four high school scholars participated in the five week program at Penn State. The Governor's School for Agricultural Sciences includes introduction and experience in many different agricultural disciplines. There are several parts of the program which are considered "core courses". The core courses are fundamental instruction given to all participants. "Radioisotope Applications in Agricultural Research" is one of the core courses in the program. This eight hour course was conducted at Penn State's RSEC by Candace Davison of the RSEC staff. Willie Kelty, a staff member of the Energy Technology Projects group, assisted during the course and Hermina Boyle, Supervisor of the Low-Level Radiation Monitoring Laboratory, provided a session on detection of radiation in the environment including radon gas. The students performed a series of experiments focusing on the fundamentals of radiation interaction and principles of radioisotope applications. These experiments included a demonstration of a cloud chamber; penetrating ability of alpha, beta and gamma radiation; half-life calculation and gamma ray spectroscopy. The importance of statistics in taking data and other applications of radioactive materials in research were discussed. The students were also given a tour of the reactor facility.

The Nuclear Concepts and Technological Issues Institute (NCTII) was conducted from July 8 - August 2, 1991 at the University Park campus. The Nuclear Concepts program was designed to prepare secondary science educators to teach the basics of nuclear science, radiation and applications and is offered as a special topics course in nuclear engineering (NucE 497B). The program was developed in 1970 and has been conducted every summer since that time. Thirty-seven secondary science teachers from eight different states (Arizona, Maryland, Massachusetts, New Jersey, New York, Ohio, Pennsylvania, and West Virginia) and Korea participated in the program. In addition, two teachers from Hungary were able to present information to the participants about their nuclear science education and observe part of the course during their stay in the U.S.

Support for the program included funding for eighteen participants through a grant from the National Science Foundation. Full sponsorship of eighteen participants was provided by Baltimore Gas and Electric Company, Bechtel Corporation, Chem-Nuclear Systems Inc., Cleveland Illuminating Company (Perry Nuclear Power Plant), Duquesne Light Company, Edison Electric Institute, General Electric Company, Gilbert Commonwealth, Haliburton NUS Environmental Corporation, Korea Atomic Industrial Forum, Limerick and Peach Bottom Community Education Program (through the Philadelphia Electric Company), New York Power Authority, New York State Electric and Gas Company and Westinghouse Electric Corporation. Full support for one teacher was provided through funding from Edison Electric Institute and the Lewisburg Area High School. Materials were obtained from the U.S. Department of Energy, USCEA, ANS and other sources. General Electric Company donated many educational materials to the course including a full-size Chart of the Nuclides and booklet to each participant. Tennelec/Nucleus provided a loan of educational counting equipment and hosted the evening reception for participants and sponsors.

The institute was coordinated by Candace Davison and was conducted through Penn State's Continuing Education Office. Joseph Bonner presented the fundamental nuclear science lectures. Other instruction was provided by Nuclear Engineering department personnel and Rodger Granlund, University Health Physicist. Guest speakers from government, research and industry provided expertise for the technical and issues sessions. Guest speakers included Ms. Carol Hanlon from the U.S. Department of Energy, Office of Civilian Radioactive Waste Disposal and Management, Dr. Robert Meyer from Chem-Nuclear Systems Inc., Mr. Jeffrey Baechler from General Electric Company, Mr. Fred Gigliotti from Westinghouse Electric Corporation, Dr. Grafton Chase retired professor from the Philadelphia College of Pharmacy and Science, Dr. Ralph Mumma distinguished professor of environmental quality and Dr. Warren Witzig professor emeritus of nuclear engineering.

Laboratory experiments are an important aspect of the institute as the teachers are able to have hands-on experience with radioactive materials. The laboratories were conducted at the RSEC under the direction of the RSEC and Health Physics personnel. Guy Anderson, a chemistry teacher from the Bald Eagle Area School District was in charge of the laboratories and was assisted by Craig Munnell, a physics teacher from Bellefonte Area School District. Both teachers are graduates of the Nuclear Concepts program. The laboratory experiments and demonstrations included: characteristics of ionizing radiation, radionuclide handling, neutron activation of Indium, complex decay of Silver-110 and Silver-108, neutron radiography and the approach to critical experiment. Discussion and problem solving sessions along with a field trip to a radiation processing facility, a tour of Medical Applications including an MRI and a visit to either Three Mile Island Unit 1 (a PWR) or Susquehanna Steam Electric Station (a BWR) were included in the schedule.

Evaluations from the participants were very positive concerning the course. As in previous institutes, the participants in NCTII were encouraged to return with their students for a day of experiments at the RSEC. Two follow-up programs were conducted for past participants of the Nuclear Concepts course during the month of May. One of the sessions was held as part of the American Nuclear Science Teachers Association meeting at Argonne National Laboratory and the other session was held at Penn State's RSEC to demonstrate the new digital control system and address topics of interest not covered during the four-week course.

The University Reactor Sharing Program is sponsored by the U.S. Department of Energy. The purpose of this program is to increase the availability of the university nuclear reactor facilities to non-reactor owning colleges and universities. The main objectives of the University Reactor Sharing program are to strengthen nuclear science and engineering instruction and to provide research opportunities for other educational institutions including universities, colleges, junior colleges, technical schools and high schools.

Experiments were conducted at the RSEC for students from the University of Pittsburgh at Greensburg.

A total of 328 students and teachers from 19 high schools and 1 college came to the RSEC for experiments and instruction. (see Table 5). Candace Davison and Lois Lunetta were the main instructors for the program. Other instruction and technical assistance for experiments were provided by Dale Raupach, Dan Hughes and Ken Sahadewan.

The RSEC staff and facilities provided educational opportunities along with a tour for student and teacher workshops, many of which were conducted as a part of Penn State Continuing Education Programs. The student programs included: the Kodak BEST (Business, Science, Engineering and Technology) program, the SEE the Future program and the Upward Bound program for minority and "at risk" students. Thirty-eight teachers from the Harrisburg area

participated in a full day of experiments as part of the course "Exploring the Nuclear Option". Twenty-seven teachers from the Enter-2000 program received instruction and toured the facility to learn more about nuclear energy and related careers.

In addition to the full or half-day programs with experiments, educational tours were conducted for students, teachers, and the general public. All groups, including the reactor sharing groups, who toured the facility are listed in Appendix B. The RSEC operating staff and Nuclear Engineering Department conducted 92 tours for 2,715 persons.

Involvement of the reactor personnel and the role of the reactor in educational programs was recognized this past year when Candace Davison, president of the American Nuclear Science Teachers Association, was invited to present several talks on the role of research reactors in nuclear science education and the impact on career decisions in nuclear engineering. One talk was for the American Nuclear Society Conference in Boston, Massachusetts. The other invitation was to represent ANSTA at the 100 year celebration of the Roland Eötvös Physics society in Hungary and to help Hungary establish a Nuclear Science Teachers Organization. Dr. Edward Teller was the keynote speaker at the conference.

The RSEC was used by several Nuclear Engineering and other courses during the year.

Semester	Course	Instructor	Students	Hours
Summer 1991	SciEd 497 - Exploring the Nuclear Option	C. C. Davison	18	4
Summer 1991	NucE 497B-Nuclear Concepts	C. C. Davison	37	7
Summer 1991	NucE 444-Nuclear Reactor Operations	D. E. Hughes	4	16
Summer 1991	Food Science 313-Process Plant Product	R. B. Beelman	20	3
Summer 1991	NucE 420-Radiological Safety	E. S. Kenney	16	3
Fall 1991	NucE 451-Reactor Physics	R. M. Edwards W. A. Jester	13	46
Spring 1992	NucE 450-Radiation Detection and Measurement	M. H. Voth W. A. Jester	24	10
Spring 1992	NucE 444-Nuclear Reactor Operations	D. E. Hughes	4	17
Spring 1992	NucE 505-Reactor Instrumentation and Control	E. S. Kenney	10	6
Spring 1992	Entomology 456-Insect Pest Management	A. Hower	7	2
Spring 1992	EMch 440-Nondestructive Evaluation of Flows	B. R. Tittman	22	2
Summer 1992	SciEd 497-Exploring the Nuclear Option	C. C. Davison	20	4

In January of 1992, a total of 39 University Police Services personnel were given training and retraining sessions by C. C. Davison at the RSEC to ensure familiarity with the facilities and to meet Nuclear Regulatory Commission requirements.

During the past year, the RSEC operating staff has maintained reactor operator competence and safe facility operation through training and requalification. The RSEC and continuing education staffs have disseminated knowledge directly to the general public through tours and indirectly through programs such as Nuclear Concepts for high school teachers. Many educational opportunities have been provided to students in university courses both nuclear and non-nuclear.

TABLE 5

University Reactor Sharing Program
College and High School Groups
1991-1992 Academic Year

Those who came to the RSEC for experiments received instruction on the basics of radiation and nuclear energy and received a tour of the facility. All groups either conducted the approach to critical experiment or saw a demonstration with the reactor. Most groups also did one of the other experiments listed below.

Gamma Ray Spectroscopy
Neutron Activation and Complex Decay of Silver
Barium-137m Decay or Silver Decay
Neutron Activation Analysis
Relative Stopping Powers for α, β and γ in Air, Aluminum and Lead

Month		School and Teacher	Number of Students & Teachers
November	18	Johnsonburg/Kane High School JoAnn Castle	14
	19	Punxsutawney High School William Stuchell	15
December	4	Greensburg - Salem HS Cheryl Harper	20
	16	Carlisle HS Robert Barrick, Kenneth Egolf	20
January	17	Berlin High School Neil Crowell	5
	17	Jersey Shore High School James Allen	14
March	9	Redland High School Robert Lighty	19
	18	Daniel Boone High School Larry Tobias, Janice Lenhart	15
	30	Berwick High School Jeff Snyder	13
April	1	Wyomissing High School Charles Bell	17
	3	Marion Center John Petrosky	9
	8	Northern Bedford Yvette Blair	21
	8	Carmichael High School Pat Gibson	21
	15	Bellefonte High School Craig Munnell	27
	20	State College High School Linda Gardner	10
	24	St. Mary's High School William Scilingo	20

TABLE 5

University Reactor Sharing Program
College and High School Groups
1991-1992 Academic Year
(Continued)

Month		School and Teacher	Number of Students & Teachers
April	24	Ridgway High School Ernest Koos	17
May	6	Muncy High School Harold Shrimp	34
June	5	University of Pittsburgh Dr. Zalenskiewicz	9
	8	Westmont Hilltop Tom Moore	8

RADIONUCLEAR APPLICATIONS LABORATORY

VII. RADIONUCLEAR APPLICATIONS LABORATORY

Personnel of the Radionuclear Applications Laboratory provide consulting and technical assistance to those University research personnel who wish to utilize some type of radionuclear technique in their research. The majority of these research projects involve some sort of neutron activation procedure, but the staff is qualified to provide services in radioactive tracer techniques, radiation gauging, radiation processing and in the production of radioisotopes for laboratory, radionuclear medicine and industrial use.

Approximately 133 irradiations of semiconductors were made during the last year for several electronic companies. Laboratory personnel prepared each group of samples for irradiation, provided fast neutron dosimetry, determined the radioisotopes produced in the devices, packaged and shipped the devices back to the companies. In addition to semiconductors, many analyses were performed for other industrial customers.

Laboratory personnel continue to supply support for the operation of the RSEC doing analysis of water, air monitor filters and various types of other samples. During the last year, both thermal and fast neutron dosimetry measurements were made for regularly used irradiation facilities and for special irradiation facilities built by experimenters.

During the year, two new multichannel analyzer-PC computer systems were purchased. One system was used to replace on old system which had been used for poolside analysis of samples being released. The new analyzer system has the capability of doing a quantitative isotope analysis of the radioactive material in the sample. Analyses and a hard copy printout of the results will be available in the reactor bay. The old system required an analyst to be present in Room 4, approximately 200 feet from poolside.

The second system purchased has the software capability of doing quantitative neutron activation analysis of samples. The system, which includes a new high resolution - high efficiency intrinsic germanium detector, has been placed in Room 2A. Placing the system in this room has a twofold benefit over the old location. It is located in an area where the radiation background level is lower and it eliminates the need for the experimenter to carry irradiation samples from the fume hood in Room 2 through two door ways and across a hallway to get to the counting system. This lowers the chances of spreading radioactive contamination.

At this time, neither of the systems has been fully integrated into normal everyday uses by laboratory personnel, but progress is being made to make them completely operational.

A project has been initiated to do a complete recalibration of the reactor neutron energy spectrum. To this end new flux monitoring foils have been purchased so that the entire neutron energy spectrum can be documented. The procedure will involve approximately two dozen different irradiations of foils, counting of the foils and determination of the neutron flux at the energy monitored by each particular foil. This foil information will then be analyzed by Penn State using computer programs developed at national laboratories. John G. Kelly of Sandia National Laboratories will do a similar computer analysis of the foil information which will be supplied to him. This neutron energy spectrum analysis will be done following applicable ASTM procedures.

MONITORING LABORATORY

LOW LEVEL RADIATION

VIII. LOW LEVEL RADIATION MONITORING LABORATORY

The staff of the Low Level Radiation Monitoring Laboratory (LLRML) provides analytical and environmental monitoring services to community water suppliers, private laboratories, utilities and researchers at the University.

The LLRML was established in 1979 to assist the water supply companies of Pennsylvania in meeting their Safe Drinking Water Act requirements. It is currently certified by the Pennsylvania Department of Environmental Resources (PA DER) to perform gross alpha, gross beta, radium-226 and radium-228 analyses on drinking water. The LLRML is also a PA DER certified radon laboratory capable of analyzing charcoal canisters.

One requirement for maintaining PA DER certification is participation in the U.S. Environmental Protection Agency's (EPA) Environmental Radioactivity Laboratory Intercomparison Studies Program and the U.S. EPA National Radon Measurement Proficiency Program. These programs involve the analysis of numerous blind samples which have been spiked with the radionuclides for which the laboratory is certified. Results from these analyses are then submitted for comparison with all other participating laboratories.

Most of the work performed at the LLRML involves the analysis of water samples for natural radiation (gross alpha, radium-226, radium-228 and radon) and the analysis of charcoal canisters for airborne radon. Other analytical capabilities of the laboratory include strontium-89, strontium-90, radon and tritium analysis of water samples and gamma-ray spectroscopy analysis of various sample media. The laboratory can also provide environmental monitoring services and spiked sample preparation services to utilities, and conduct research both independent and in cooperation with other University researchers.

THE ANGULAR CORRELATIONS LABORATORY

IX. THE ANGULAR CORRELATIONS LABORATORY

The Angular Correlations Laboratory has been in operation for approximately 6 years. The laboratory, which is located in Room 116 and Room 4 of the RSEC, is under the direction of Professor Gary L. [illegible]. The laboratory contains two spectrometers for making Perturbed Angular Correlation (PAC) measurements. One apparatus, which has been in operation for six years, measures eight coincidences concurrently using cesium fluoride detectors. A second spectrometer was acquired last year, and it measures four coincidences concurrently using barium fluoride detectors. The detectors and electronics provide a nominal time resolution of 1 nsec FWHM, which places the measurements at the state-of-the-art in the field of Perturbed Angular Correlation Spectroscopy.

Currently, Penn State has a unique research program that uses PAC Spectroscopy to characterize technologically important electrical and optical materials. This program represents the synthesis of ideas from two traditionally very different branches of chemistry, materials chemistry and nuclear chemistry. Although the scientific questions are germane to the field of materials chemistry, the PAC technique and its associated theoretical basis have been part of the fields of nuclear chemistry and radiochemistry for several decades. Two federal agencies, the National Science Foundation and the Office of Naval Research, are sponsoring this program.

The PAC technique is based on substituting a radioactive probe atom such as either ^{111}In or ^{181}Hf into a specific site in a chemical system. Because these atoms have special nuclear properties, the nuclear (electric quadrupole and magnetic dipole) moments of these atoms can interact with the electric field gradients (efgs) and hyperfine magnetic fields produced by the extranuclear environment.

Static nuclear electric quadrupole interactions can provide a measure of the strength and symmetry of the crystal field in the vicinity of the probe nucleus. In the case of static interactions, the vibrational motion of the atoms in the lattice is very rapid relative to the PAC timescale, i.e., 0.1-500 nsec. As a result, the measured efg appears to arise from the time-averaged positions of the atoms, and the sharpness of the spectral lines reflects this "motional narrowing" effect. In contrast to static interactions, time-varying interactions arise when the efg fluctuates during the intermediate-state lifetime. These interactions can provide information about defect and ionic transport. The effect of the efg fluctuating in either strength or direction, which can be caused, for example, by ions "hopping" in and out of lattice sites, is to destroy the orientation of the intermediate state. Experimentally, this loss of orientation appears as the attenuation or "smearing-out" of the angular correlation. And, often a correspondence can be made between the rate of attenuation and frequency of the motion that produced the attenuation.

Magnetic hyperfine interactions, which can be measured in ferromagnetic and paramagnetic bulk and thin-film materials, are used to study the effects of defects and lattice distortions in metal and semiconducting structures that have nominal cubic symmetry. The general approach is to measure the magnetic hyperfine interaction in a material with few defects. The cubic symmetry requires that the electric quadrupole interaction vanishes. When either defects or distortions are produced, a quadrupole interaction arises that attenuates the usually-well-defined magnetic interactions. Thus, the analysis of this attenuation can provide information, for example, about the type of defect that produced the quadrupole interaction.

Current Activities

During the last year, the PAC technique has been used to investigate phase transitions and local ordering in ferroelectric perovskites such as lead titanate and barium titanate. These compounds and other related materials are widely used as dielectric materials for capacitors, piezoelectric

transducer materials, and thin-film elements for random access memories. Static nuclear quadrupole interactions measured in these materials have provided new information about displacive (paraelectric-to-ferroelectric) phase transitions such as the critical behavior of the (titanium-site) electric field gradient at temperatures near the transition temperature. Time-varying interactions, which produce nuclear-spin relaxation, have provided information about order-disorder effects associated with the phase transition such as the rate of titanium-ion jumping between off-center sites in the lattice. This investigation has produced some unique evidence that supports an order-disorder model of the paraelectric-to-ferroelectric phase transitions in these structures. This evidence along with other supporting measurements indicates that the established displacive (soft-mode) model is at best incomplete and perhaps wrong. The Office of Naval Research has supported this work via a research grant.

Planned Activities

The current plans are to continue the research on the ferroelectric materials. This work will have several parallel thrusts. In particular, since few of the ABO_3 perovskites have been investigated, similar measurements need to be performed on $KNbO_3$, $KTaO_3$, and similar materials. The objectives are to extend the scope of the data base and to evaluate the effects of different B-ion valences. A particular interesting and technologically important family of ferroelectrics is the relaxor type, of which $Pb(Sc_{0.5}Ta_{0.5})O_3$ is an example. They have unusual electrical properties, and these properties are thought to be caused by local disorder in the B-ion composition. In addition, these relaxor ferroelectrics can be prepared so that they have conventional ferroelectric electrical properties. This feature means that parallel measurements can be made on relaxor-prepared and conventionally-prepared samples that have the same stoichiometry. The experimental objective is to compare linebroadening effects that can be related to relaxor disorder. This comparison could delineate whether the disorder is either a static or a dynamic effect. In another project, experiments will be performed on materials such as $BaTiO_3$ that can be prepared in a reduced, oxygen deficient form. These materials have quite different electrical properties than their stoichiometric counterparts as they are conductive. Under the proper conditions of temperature and oxygen partial pressure, oxygen vacancy transport rates would be measured. This information could lead to developing a good model for defect transport in these materials. Moreover, since defect kinetics are not well understood but are thought to be responsible for many technical problems, such a model could have a positive impact on the electronics industry.

Another important area of research in electronic materials is the characterization of chemical interactions on molecular-beam-epitaxy (MBE) produced surfaces. In principle, the PAC technique can measure the strength and symmetry of the chemical bonding of the ^{111}In probe atom on MBE-produced surfaces of gallium arsenide and other III-V materials. Currently, electron scattering is the predominant technique that is used to evaluate the morphology of MBE-produced III-V surfaces. But, these measurements do not provide any detailed, microscopic information about for example, the effects of step edges and kinks on the chemical bonding of impinging atoms on these surfaces. The PAC technique, which would use the ^{111}In probe, could be used to measure these effects. Moreover, during the last decade, a German group has shown that PAC measurements on Cu and CuIn surfaces under ultrahigh vacuum are feasible and that the measurements do provide information about chemical bonding on MBE-produced surfaces. A project of this type requires a collaboration between an expert in MBE-produced surfaces and an expert in PAC spectroscopy. Penn State has such an expert; namely, Professor David L. Miller of the Department of Electrical Engineering. The Center for Electronics Materials and Processing (of the College of Engineering) has a large state-of-the-art Varian MBE machine. But, to dope the MBE-produced surfaces, a small, dedicated ultrahigh vacuum chamber needs to be added to the existing MBE system to prevent contamination of the main system. Last year, the National Science Foundation funded this project and work is underway.

NUCLEAR MATERIALS ENGINEERING LABORATORY

X. NUCLEAR MATERIALS ENGINEERING LABORATORY

The Nuclear Materials Engineering Laboratory has two heavily shielded hot cells with master-slave manipulators for the remote handling of highly radioactive materials viewed directly through thick leaded-glass windows. Equipment is provided for impact testing, tensile testing, hardness testing, fracture toughness testing, fatigue testing, creep testing, corrosion testing, metallographic examination, positron annihilation studies, light microscopy and electron microscopy. Research has focused on plant life extension for nuclear power reactors.

RADIATION SCIENCE & ENGINEERING CENTER RESEARCH

XI. RADIATION SCIENCE AND ENGINEERING CENTER RESEARCH UTILIZATION

Research continues to be the major focus of the RSEC. A wide variety of research projects are currently in progress as indicated on the following pages. The University oriented research projects are arranged alphabetically by department in Section A. Theses, publications, papers and technical presentations follow the research description to which they pertain. In addition, Section B lists other university and industrial research utilizing the facility.

The reporting of research information to the editor of this report is at the option of the researcher, and therefore the research projects in sections A and B are only representative of the research at the facility. The projects described involved 4 technical presentations, 9 papers, 31 publications, 5 masters' theses, 11 doctoral theses and 4 bachelor's theses. The examples cited are not to be construed as publications or announcements of research. The publication of research utilizing the RSEC is the prerogative of the researcher.

Appendix A lists all university, industrial and other users of RSEC facilities, including those listed in sections A and B. Names of personnel are arranged alphabetically under their department and college or under their company or other affiliation. During the past year, 44 faculty and staff members, 34 graduate students and 5 undergraduate students have used the facility for research. This represents a usage by 15 departments or sections in 4 colleges of the University. In addition, 44 individuals from 33 industries, research organizations or other universities used the RSEC facilities.

A. PENN STATE RESEARCH UTILIZING THE FACILITIES OF THE RADIATION SCIENCE AND ENGINEERING CENTER

Chemistry Department

POLYPHOSPHAZENE HYDROGELS FOR USE AS SUPPORTS IN PEPTIDE SYNTHESIS

Participants: H. R. Allcock
A. Ambrosio
E. N. Silverberg

Services Provided: Gamma Irradiation

A series of functional poly(organophosphazenes) have been synthesized, crosslinked, and tested as potential supports for solid phase peptide synthesis. These polymers were $[NP(OCH_2CH_2OCH_2CH_2OCH_3)_x(OCH_2CH_2OCH_2CH_2NHBOC)_{2-x}]_n$, where x = 1.6, 1.0, 0.6. These polymers were synthesized by a multi-step route. In the first step, poly(dichlorophosphazene) was treated with the appropriate amount of sodium methoxyethoxyethoxide. An excess of sodium N-Boc-aminoethoxyethoxide was then added to the partially substituted polymers. In the final step of the synthesis, the Boc protecting group was removed by acid hydrolysis. These polymers were then crosslinked by gamma radiation for 2.0 and 5.0 MRad. The synthetic utility of the poly(organophosphazene) gel as solid phase peptide synthesis supports was demonstrated by the syntheses of tri- and tetrapeptides. The peptides were assembled by using standard Fmoc-polyamid chemistry.

Chemistry Department

IRRADIATION INDUCED SOLID STATE POLYMERIZATION OF CYCLOTRI PHOSPHAZENES

Participants: H. R. Allcock
U. Diefenbach
S. R. Pucher

Services Provided: Gamma Irradiation

High energy gamma irradiation can cause solid state polymerization of several cyclic compounds such as trioxane, that coverts to poly(oxymethylene) and hexachlorocyclotri phosphazene $(NPCl_2)_3$ that forms the corresponding polyphosphazene $(NPCl_2)_n$. The yields of the so obtained polyphosphazenes, however, have been low.

To investigate, if gamma irradiation can be used as a method to polymerize substituted cyclotriphosphazenes and heterophosphazenes, 18 samples of partially and fully substituted phosphazenes that contain aikylamino, asylamino, alkyl, asyloxy, ferrocenyl and trifluorethoxy groups as well as carbon and sulfur containing ring systems were purified to obtain highly crystalline compounds. Those were exposed to gamma irradiation at room temperature (dose rate 5 MRad).

The effect on the polymerization behavior was examined by ^{31}P NMR spectroscopy. However, no polymeric materials could be obtained under these conditions.

Chemistry Department

POLY(ORGANOPHOSPHAZENES) WITH POLY(ALKYETHERSIDE GROUPS): A STUDY OF THEIR WATER SOLUBILITY AND SWELLING CHARACTERISTICS OF THEIR HYDROGELS

Participants: H. R. Allcock
S. R. Pucher
M. L. Turner
R. J. Fitzpatrick

Services Provided: Gamma Irradiation

Five different poly[(alkyl ether)phosphazenes] were synthesized for studies of their water solubility as well as the swellabilities of their corresponding hydrogels in aqueous media. They are: poly[di(methoxyethoxy)phosphazene], poly[di(aminoethoxyethoxy)phosphazene], poly[di(methoxyethoxyethoxy)phosphazene], poly[di(ethoxyethoxyethoxy)phosphazene], and poly[di(butoxyethoxyethoxy)phosphazene]. Lower critical solution temperatures (LCST) were detected for four of the polymers. This phenomenon was independent of polymer concentration. However, poly[di(aminoethoxyethoxy)phosphazene] possessed no LCST in aqueous media and remained fully soluble at all polymer concentrations. Hydrogels of these polymers were prepared by subjecting them to gamma radiation (1 MRad, 5 MRad, and 10 MRad). The crosslinked polyphosphazenes behaved in a similar manner to their soluble counterparts. As the temperature of the aqueous media was increased, the hydrogels became opaque and released water. During these experiments, the percentage of water lost by the hydrogels was independent of both the pH of the aqueous media and the radiation dose received by the gels. No detectable decomposition of the soluble polymers was found nor was any loss of integrity of the hydrogels detected through several heating and cooling cycles. This solubility phenomenon was characteristic only of the interaction with water and was not detected in organic solvents. Potential biomedical applications of these materials exist.

Doctoral Thesis:

Pucher, S., and H. R. Allcock (advisor). Bioerodible and Biostable Poly(organophosphazenes): Biomaterials for Antibacterial Coatings and Drug Delivery Systems. In progress.

Publication:

Pucher, S., H. R. Allcock, M. Turner and R. Fitzpatrick. Poly(organophosphazenes) with Poly(alkylether) Side Groups: A Study of Their Water Solubility and the Swelling Characteristics of Their Hydrogels. Accepted to *Macromolecules*.

Chemistry Department

INCLUSION POLYMERIZATION

Participants: H. R. Allcock
E. N. Silverberg
G. K. Dudley
S. R. Pucher

Services Provided: Gamma Irradiation

Host-guest phenomenon has been known for many years. One type of these adducts is clathrates or molecular inclusion compounds. Clathrates are crystalline solids in which guest molecules occupy cavities or tunnels within the host lattice. The guest is held by steric and van

der Waals forces only, with no formal bond between the guest and host. Inclusion chemistry has been known for many years. Urea, thiourea, cyclodextrins, perhydrotriphenylene and zeolites have all been shown to have inclusion behavior.

Cyclophosphazenes are a class of inorganic ring systems with alternating phosphorus and nitrogen atoms in the ring. It was found that certain spirocyclotriphosphazenes show molecular inclusion phenomenon. The synthesis and inclusion properties of tris(ophenelenedioxy)-cyclotriphosphazene (**1**), tris(2,3-naphthalenedioxy)cyclotriphosphazene (**2**) and tris(1,8-naphthalenedioxy)cyclotriphosphazene (**3**) are well known. Compounds **1-3** form clathrate adducts with organic molecules when recrystallized from organic solvents. Furthermore, pure **1** forms inclusion adducts spontaneously when brought in contact with the liquid or vapor phase of the guest component. Polymerization of organic monomers within **1** and **2** by ^{60}Co gamma radiation has been reported. In many cases, macromolecules formed in this manner have been stereoregular. The structural aspects of compounds **1-3** as well as their clathrate adducts have been examined by x-ray single-crystal structure studies.

The aim of this work is to synthesize spirocyclophosphazenes and continue the investigation of polymerization of organic monomers within the clathrate tunnels.

Doctoral Thesis:

Silverberg, E. N., and H. R. Allcock (advisor). Phosphazene Clathrate Systems. In progress.

Chemistry Department

SURFACE MODIFICATION OF POLYPHOSPHAZENES BY GAMMA RADIATION - INDUCED GRAFTING

Participants: H. R. Allcock
D. E. Smith

Services Provided: Gamma Irradiation

Synthetic polymers are used in a wide range of materials applications. The suitability of a polymer for a particular application may depend upon its possessing both the desired bulk properties and also its having a specific surface nature. The ability to choose a polymer with desired bulk properties and to tailor its surface chemistry to suit the application is therefore an important development.

The polyphosphazene family is particularly suited to this approach. The properties of a phosphazene polymer are largely dependent upon its side group substituents. Macromolecular substitution, the common route to organophosphazene polymers, allows fine control over bulk properties, such as crystallization, glass transition temperatures and solubility. The greater chemical stability of the P-N backbone over purely organic analogues allows reactions such as side group substitutions and radiation crosslinking to be carried out with a lower likelihood of chain cleavage.

Polyphosphazene elastomers with saturated and/or unsaturated hydrocarbon side chain substituents have been synthesized, including alkyl phenoxy, alkyl ether and allyl phenoxy groups. Films of these elastomers, coated with polydimethylsiloxane (PDMS) and other siloxanes, are exposed to gamma radiation in controlled doses. The production and reaction of radicals within both polymer types is expected to result in overall crosslinking and covalent grafting at the siloxane-phosphazene interface.

Surface properties of the modified films, such as surface energy, hydrophobicity and biocompatibility, are to be investigated.

Chemistry Department

SYNTHESIS AND CHARACTERIZATION OF ION SELECTIVE POLYPHOSPHAZENE INTERPENETRATING POLYMER NETWORKS

Participants: H. R. Allcock
K. B. Visscher

Services Provided: Gamma Irradiation

The synthesis of several new ion specific interpenetrating polymer networks composed of polyphosphazenes and ion specific organic polymers is reported. Full, sequential IPNs were prepared from cross-linked poly[bis(2-(2-methoxyethoxy)ethoxy)phosphazene], poly[bis(propyl oxybenzoate)phosphazene] and several organic polymers including poly(acrylic acid), poly(sulfonic acid sodium salt), poly(diundecylenylphosphinate) and poly((pmethylimino diacetoxy)styrene). These materials were characterized by NMR and IR spectroscopy and differential scanning calorimetry (DSC). The complexed metal ions were analyzed by elemental analysis, electron microscopy and x-ray microanalysis.

There exists a need to develop polyphosphazene interpenetrating polymer networks (IPN) which function as ion exchange or ion filtration materials for both aqueous and organic media. These materials could find many applications in both biomedicine and environmental science. IPNs swell, but are insoluble in both aqueous and organic environments. This would enable ion exchange or filtration to take place over a much greater surface area compared to standard ion exchange materials in a variety of solvent systems.

Ion exchangers are cross-linked, insoluble, high molecular weight polyelectrolytic materials which exchange mobile ions for ions of equal charge from the surrounding media. The ion exchange process is stoichiometric and reversible. Ion exchange materials may be considered supramolecular acids or bases containing a high molecular weight cation which normally take the form of powders, beads, granules or other forms with limited surface area.

Many ion exchangers are, in reality, acidic or basic derivatized forms of common cross-linked organic polymers such as polystyrene. As such, the ion exchanger is dependent upon the functional groups present in the cross-linked matrix. Many well known commercial cation exchangers contain the following acidic functionalities incorporated into their matrices:

1. $-SO_3^-$
2. $-CO_2^-$
3. $-O^-$
4. $-PO_3H$
5. $-AsO_3^{2-}$
6. $-SeO_3^-$

Several of these materials possess high solubility in water and therefore are unsuitable for ion exchange. This solubility problem may be rectified in a number of different ways including: 1) cross-linking the polymer to promote insolubility, 2) the derivatized monomer may be incorporated into a co-polymer system and 3) the polymer may be prepared as part of an interpenetrating polymer network (IPN).

Interpenetrating polymer networks are multicomponent polymer systems which may be prepared by polymerizing and cross-linking a monomer within the swollen, cross-linked matrix of a second polymer. The two polymers may form an intimate mixture which would lead to a greater probability of intermolecular interactions between the species. Once prepared, the IPN is insoluble, but swellable in aqueous or organic media. As such, IPNs might provide a greater surface area for ion exchange for a smaller amount of material used. The interpenetrating polymer networks for this project would consist of a cross-linked poly(organophosphazene) matrix and an organic monomer with one of the aforementioned acid functionalities.

Poly(organophosphazenes) comprise a broad, well known class of inorganic/organic polymers possessing a flexible backbone of N=P units. Phosphazenes are unique in that their properties

and applications may be tailored by the choice of side groups on the polymer. Poly(organophosphazenes) have many and varied properties which underlie their uses as biomaterials, non-linear optical materials, pre-ceramics, and as non-burning, oil resistant, low temperature elastomers.

We have reported previously the preparation and characterization of IPNs containing poly[bis(2-(2-methoxyethoxy)ethoxy)phosphazene] or poly[bis(propyloxybenzoate) phosphazene] and various organic polymers including polystyrene, poly(methyl methacrylate), polyacrylonitrile and poly(acrylic acid). In all cases, the phosphazene polymers served as the cross-linked polymer matrix. As part of our program to synthesize new materials with novel macromolecular properties, we report the preparation of several well characterized IPNs capable of ion exchange or ion filtration containing poly(organophosphazenes) and organic polymers containing acid functionalities.

Doctoral Thesis:

Visscher, K. B., and H. R. Allcock (advisor). Synthesis and Characterization of Poly(organophosphazene) Alloys. In progress.

Publications:

Allcock, H. R., I. Manners and K. B. Visscher. Polyphosphazene - Organic Polymer Interpenetrating Polymer Networks. Submitted to *Chemistry of Materials*, 1992.

Allcock, H. R., K. B. Visscher and I. Manners . Synthesis and Characterization of Poly(organophosphazene) Interpenetrating Polymer Networks. *ACS Symp Ser* . In Press, 1991.

Fitzpatrick, R. J., K. B. Visscher and H. R. Allcock. Thin Layer Grafts of Poly[bis(methoxyethoxyethoxy)Phosphazene on Organic Polymer Surfaces. *Chemistry of Materials*. In Press, 1992.

Allcock, H. R., and K. B. Visscher. Synthesis and Characterization of Poly(organophosphazene) Blends. Submitted to *Chemistry of Materials*, 1992.

Dairy and Animal Science

EFFECT OF OVIDUCT FLUID COMPOSITION ON SPERM MOTILITY AND CAPACITATION.

Participants: G. Killian
D. Zaczek

Services Provided: Gamma Irradiation

This lab was attempting the production of hybrid cell lines which would secrete monoclonal antibodies directed against proteins found within the bovine oviduct. In efforts to maximize survival of hybrid clones we incorporated a feeder cell layer as part of our standard fusion protocol. This feeder cell layer consisted of murine fibroblast cells (L929 cells purchased through the ATCC). A continuous culture of these cells was maintained in our lab. One day prior to fusion, a 75% confluent monolayer of L929 was harvested in RPMI 1640 culture media and washed two times in the same media. Subsequently the cells were brought to the Breazeale reactor and gamma irradiated with 10,000 rad to prevent their proliferation. They were returned to our lab and resuspended in RPMI 1640 supplemented with HAT (5×10^{-3} M hypoxanthine, 2×10^{-5} M aminopterin, 8×10^{-4} M thymidine) and adjusted to a density of 5×10^4 cells/mL. One mL aliquots of the feeder cell suspension were added to each well of four 24 well tissue culture plates and incubated overnight at 37°C with 5% CO_2. The next day, fused cells were added to the already established plates and clones allowed to develop.

Hybrid lines thus produced were expanded to the point they could be frozen down in liquid N_2. We are currently subcloning the lines and assessing the antibodies produced to determine their potential use in our lab.

Sponsor: USDA-NRICGP grant at $250,000

Food Science Department

IRRADIATION OF TURKEY SKIN TO KILL NATURAL MICROFLORA

Participants: S. Poores
J. W. Kim

Services Provided: Gamma Irradiation

In this study, irradiation was used for preparation of skin samples. To get sterile skin samples, several dosages were tried and a minimum dosage of 0.5 MRads was determined best for use in later studies.

Doctoral Thesis:

Kim, J. W., and S. Poores, advisor. Effect of Three Defeathering Systems on the Morphology of Turkey Skin as Related to Attachment of Salmonella typhimurium. In progress.

Sponsor: Pennsylvania Department of Agriculture, $66,198

Geosciences Department

PETROLOGY & GEOCHEMISTRY OF THE ROCKY BOY STOCK, BEARPAW MOUNTAINS, MONTANA

Participants: D. Eggler
S. Shank
L. Kump

Services Provided: Neutron Irradiation

The origin of alkaline and subalkaline magmas in central Montana is unclear. There are three possible sources for the magmas; subcontinental lithosphere, asthenosphere and the subducting Farallon Plate. However, the relative contributions, if any, of each possible component is poorly constrained. To help clarify this question, a suite of unusual potassic alkaline rocks from the Rocky Boy Stock in the Bearpaw Mountains in north-central Montana is being studied. The three possible sources are characterized by distinct trace-element signatures The subcontinental lithosphere beneath central Montana is distinguish d by high Ba and extreme enrichment in the light rare-earth elements, La, Ce and Nd. The asthenosphere is characterized by high concentrations of Ta, Ti and Nb. In contrast, subduction-related magmas are distinguished by strong depletions in Ta, Ti and Nb, but are enriched in Cs, Th and Rb. The trace-element data determined by INAA will aid in the identification of the source(s) of the magmas, and will provide constraints on the relative proportion derived from each possible source.

Doctoral Thesis:

Shank, S., and D. Eggler, advisor. Petrology and Geochemistry of the Rocky Boy Stock, Bearpaw Mountains, Montana. In progress.

Sponsor: National Science Foundation

Industrial Engineering

THE EXPERIMENTAL DETERMINATION OF THE NEUTRON CROSS SECTION FOR SELECTED SOLVENTS

Participants: S. H. Levine
D. F. Poeth
C. Ruud
D. E. Hughes

Services Provided: Neutron Radiography and Radiation Counters

This experimental program is to determine the macroscopic neutron cross section of various solvents useful in neutron radiographic inspection. A Triga reactor was used as a thermal neutron source with a Reuter Stokes fission chamber as the neutron detector. Selected solvents were placed in specially fabricated glass vials of low neutron cross section. The vials of fluids were placed in a special holder on a motorized table which allowed each fluid to be remotely positioned in the neutron beam. A statistical experimental design was generated to quantitatively determine each fluid's macroscopic neutron cross section. Because polyenergetic neutrons are used in neutron radiographic inspection, no attempt was made to generate a monoenergetic beam for this investigation. Moderator tank temperature, core fuel temperature, neutron flux, gamma flux and reactor power were recorded over time and plotted.

The results of this experiment provided a quantitative measure of the mean and standard deviation of the macroscopic neutron cross section for the 9 fluids investigated. The measured cross section for distilled water was in close agreement with published values.

Doctoral Thesis:

Poeth, D., and C. Ruud, advisor. The Development of an Optimized Neutron Opaque Penetrant for the Evaluation of Manufacturing Damage in Monolithic and Composite Materials. In progress.

Mechanical Engineering

FLUID FLOW VISUALIZATION WITH NEUTRON RADIOGRAPHY

Participants: D. Sathianathan
J. M. Cimbala

Services Provided: Neutron Radiography

Two short term projects were conducted at the neutron radiography facility:

1. Examination of breathing regulators using NR for Mine Safety Appliances Company, Pittsburgh. This involved studying the behavior of the diaphragms within the face-mask and belt-mounted regulators during operation. Real-time radiographs were acquired to visualize displacement and frequency of diaphragm oscillation for extreme test conditions.

2. Lead-bismuth liquid metal flow experiments with Professor Takenaka and his co-workers from Kobe University, Japan. NR techniques were used to visualize natural and forced convection flow patterns in molten lead-bismuth. The flow patterns were observed using neutrally buoyant particles in a 1-D stainless steel test-section. The particles were clearly visible and could be easily tracked using the real-time (30 frames/sec.) imaging system. Using these results, Professor Takenaka is hoping to secure funding for further research from the Japanese agencies.

Doctoral Thesis:

Sathianathan, D., and J. M. Cimbala, advisor. Fluid Flow Visualization with Neutron Radiography. 1992.

Paper:

Sathianathan, D., and J. M. Cimbala. Theoretical Predictions for Imaging Shock Waves in Gases Using Neutron Radiography. Proceedings of the Fourth World Conference on Neutron Radiography, San Francisco, CA. May 11-14, 1992.

Metals Science and Engineering

PLANT LIFE EXTENSION TECHNOLOGY: NON-DESTRUCTIVE REACTOR MATERIALS EMBRITTLEMENT MONITORING USING POSITRON ANNIHILATION LIFETIME SPECTROSCOPY

Participants: M. P. Manahan
P. D. Freyer

Services Provided: Hot Cell Lab, Radiation Counters, Machine Shop and Electronics Shop

Reactor pressure vessels and core internals are neutron irradiated during operation and consequently are subject to radiation-induced embrittlement. It is highly desirable for future end-of-license (EOL) extension planning to be able to monitor the material degradation and to accurately model the embrittlement process at critical locations on a regular basis.

This research program is in the process of investigating the effects of neutron irradiation on ferritic reactor pressure vessel steels using positron annihilation spectroscopy (PALS). Positron annihilation techniques have proven useful as a non-destructive probe for studying microstructural defects such as microvoids and precipitates in solids. For life extension purposes, detection and quantification of microvoid densities is essential to the characterization of the steel embrittlement. The positron annihilation system is used to measure the microvoid density in neutron irradiated pressure vessel steel using a free-volume microprobe (FVM). A FVM is capable of extremely sensitive detection of minute changes in the molecular free volume of a material. The key to the FVM is the very precise measurement of positron lifetime in the material of interest. The technique is so sensitive to electron density that localized changes, such as the introduction of microvoids due to neutron bombardment, can be readily detected. This data, along with other microstructural measurements (light microscopy, scanning electron microscopy (SEM) and transmission electron microscopy (TEM)) will be used to develop physically-based models which can predict material behavior such as strength, ductility and fracture toughness.

To date, Phase I of the project has been completed. This work involved using PALS on a pressure vessel steel exposed to a relatively low fluence. The material was provided by Niagra Mohawk Power Corporation. PALS detected a readily measurable difference in positron lifetime between the unirradiated and irradiated states. Specifically, an additional lifetime component was measured in the irradiated material; this component is believed to be due to microvoids which were produced during the neutron damage cascade. TEM has been used to investigate the various phases and precipitates present in the unirradiated and irradiated steel and electron diffraction patterns were used in order to identify these phases. SEM has also been used to study the fracture surfaces of both the unirradiated and irradiated material. These characterization techniques showed no difference in microstructure or fracture mechanisms between the unirradiated and irradiated material.

Phase II of the project has recently been initiated. The material used for this portion of the study has been supplied by Westinghouse Electric Corporation. Once again, the material is a ferritic pressure vessel material, however, these particular samples have been exposed to several different

fluence levels, all of which are orders of magnitude higher than the Phase I material. In addition, these samples have been subjected to a series of different anneal schedules and have various chemical compositions. PALS measurements are currently being done on this set of samples to determine if the technique is capable of measuring the differences in defect density present after each irradiation and anneal. This portion of the project does not involve any destructive measurements such as light microscopy, SEM or TEM.

Master's Thesis:

Freyer, P. D., and M. P. Manahan, advisor. Non-Destructive Reactor Materials Embrittlement Monitoring for Plant Life Extension (PLEX) Applications. In progress.

Technical Presentations:

Freyer, P. D. Plant Life Extension Technology: Non-Destructive Reactor Materials Embrittlement Monitoring Using Positron Annihilation Lifetime Spectroscopy. Midwest/Northeast American Nuclear Society Student Conference, University of Michigan. 1992.

Freyer, P. D. Non-Destructive Reactor Materials Embrittlement Monitoring for Plant Life Extension (PLEX) Applications. Graduate Seminar Series, Metals Science & Engineering Department. 1991.

Freyer, P. D. Non-Destructive Reactor Materials Embrittlement Monitoring for Plant Life Extension (PLEX) Applications. Cooperation Research Program, Metals Science & Engineering Department. 1991.

Sponsor: Project FERMI

Nuclear Engineering

NEUTRON ABSORPTION AND CORROSION PROPERTIES OF BORATED ALUMINUM

Participants: A. J. Baratta
S. Lu
H. Pickering

Services Provided: Neutron Irradiation, Laboratory Space and Machine Shop

Borated aluminum is a candidate neutron absorber for use in the storage of spent nuclear fuel. The research effort sought to evaluate the corrosion and neutron absorption properties of the material in a variety of storage pool environments.

Studies were conducted for both BWR & PWR pool conditions under both normal and abnormal PH, temperature and irradiation levels. Subsequent microscopic assessments were made of the materials post exposure conditions and neutron attenuating abilities.

Sponsor: Eagle-Pitcher Corporation $30,000

Nuclear Engineering

NEUTRON ENERGY SPECTRUM ANALYSIS

Participants: A. J. Baratta
D. C. Raupach
M. Oliver

Services Provided: Radiation Counters and Flux Monitoring

A cooperative effort between Mark Oliver of the Army Pulsed Reactor Facility (APRF) at Aberdeen, Maryland, and radionuclear applications personnel at the RSEC has been undertaken in an effort to gain expertise in doing neutron energy spectrum analyses.

Necessary neutron activation foils and appropriate shielding covers for doing a calibration of the six inch, lead shielded, round irradiation tube at the RSEC were supplied by APRF. The foils were irradiated for predetermined times and then counted at both the RSEC counting facility and at APRF. Actual calculations for determining the neutron energy spectrum are still in progress.

Nuclear Engineering

PERTURBED ANGULAR CORRELATION (PAC) SPECTROSCOPY: EVIDENCE FOR PROBE-DOPANT INTERACTIONS IN CA-DOPED BARIUM TITANATE

Participants: G. L. Catchen
J. M. Adams
R. L. Rasera

Services Provided: Neutron Irradiation and Angular Correlations Lab

To investigate dopant- and defect- probe interactions, we have performed perturbed-angular-correlation (PAC) spectroscopy on Ca-doped barium titanate ceramics. Polycrystalline samples of barium titanate were prepared using the resin-intermediate process, and the samples were doped with Ca according to the formula $(Ba_{1-x}Ca_x)(Ti_{1-y}Ca_y)O_{3-y}$, in which $0 \leq x \leq 0.05$ and $0 \leq y \leq 0.05$. All of the samples were doped with approximately 0.1 at % of Hf, which substituted into the Ti sites and carried the $^{181}Hf \dashrightarrow {}^{181}Ta$ PAC probe radioactivity. Measurements were performed over a temperature range from laboratory temperature to ≈ 1100 K. In the ferroelectric phases, at Ca concentrations of several percent, the doping produces an increase in the Ti-site electric-field-gradient (efg) asymmetry and in the extent of spectral linebroadening. At higher Ca concentrations, the linebroadening increases further and the ferroelectric-to-paraelectric transition is not discernable. The changes in efg symmetry and spectral linebroadening, which are essentially temperature invariant, could be attributed to preferential substitution of the Ca dopant into Ba coordination spheres that are near the probe sites. In the paraelectric phase, doping at 2 at. % produces a weak perturbation that is several times stronger than the corresponding weak perturbation that non-doped samples show over the same temperature range. This result strongly suggests that O vacancies do not cause weak perturbations.

Publication:

Adams, J. M., and G. L. Catchen. Perturbed-Angular-Correlation (PAC) Spectroscopy: Evidence for Probe-Dopant Interactions in Ca-Doped Barium Titanate. *Materials Science and Engineering*. April 1992.

Sponsor: Office of Naval Research $69,000

Nuclear Engineering

HIGH-TEMPERATURE PARTITIONING OF ^{181}HF-PROBE IMPURITIES BETWEEN LI AND GROUP-V SITES IN $LiNbO_3$ AND $LiTaO_3$

Participants: G. L. Catchen
J. M. Adams
T. M. Rearick

Services Provided: Neutron Irradiation and Angular Correlations Lab

Perturbed-angular-correlation (PAC) spectroscopy was used to measure nuclear-electric-quadrupole interactions at high temperatures in ceramic ternary metal oxides, $LiNbO_3$ and $LiTaO_3$. In these ferroelectric ceramics, the ^{181}Hf --> ^{181}Ta PAC probe was carried by approximately 0.03 at. % Hf as an impurity dopant, and the PAC measurements were made over a temperature range from approximately 1300 to 1700 K, which included the ferroelectric-to-paraelectric transition for $LiNbO_3$. As we recently reported, at temperatures below ≈ 1100 K, the probe substitutes primarily into Li sites in both compounds. At higher temperatures, we find that the ^{181}Hf --> ^{181}Ta probe partitions between the Li and group-V sites. At these higher temperatures, the Li-site electric-field gradients (efgs) are characterized by high frequencies that are similar to those observed at lower temperatures. The group-V site efgs are characterized by frequencies that are approximately one-tenth the magnitude of those corresponding to the Li sites.

Publication:

Catchen, G. L., J. M. Adams and T. M. Rearick. High-Temperature Partitioning of ^{181}Hf-Probe Impurities Between Li and Group-V Sites in $LiNbO_3$ and $LiTaO_3$. Accepted for publication in the *Physical Review B*. April 1992.

Paper:

Catchen, G. L. (Presenter), J. M. Adams and T. M. Rearick. High-Temperature Partitioning of ^{181}Hf-Impurities Between Li Sites and Group-V Sites in $LiNbO_3$ and $LiTaO_3$. American Chemical Society National Meeting, Washington, DC. August 23-28, 1992.

Sponsor: Office of Naval Research $69,000

Nuclear Engineering

CALIBRATION OF A MÖSSBAUER-EFFECT SPECTROMETER

Participants: G. L. Catchen
R. J. Hanna III

Services Provided: Angular Correlations Lab and Laboratory Space

Recently, to expand research into the field of Mössbauer-effect spectroscopy, two Mössbauer-effect spectrometers were acquired. However, both units were incomplete and no data analysis software was available with either unit. Beginning in May of 1991, as an undergraduate research project, repair and calibration was begun on the more modern unit. This effort was successfully concluded in April of 1992 with the calibration of the unit and the writing of data analysis software. The B.S. thesis describes in detail the procedure and the associated theory and

equipment for calibration of a Mössbauer-effect spectrometer. It explains the theory behind resonant gamma-ray absorption and emission. The theory and working of the spectrometer are described. The data and the results of a calibration run with a Fe_2O_3 calibration disk are also presented.

Bachelor's Thesis:

Hanna, R. G., and G. L. Catchen, advisor. Calibration of a Mössbauer-Effect Spectrometer. 1992.

Nuclear Engineering

USING NUCLEAR-ELECTRIC-QUADRUPOLE INTERACTIONS TO CHARACTERIZE FERROELECTRIC-TO-PARAELECTRIC TRANSITIONS IN $BaTiO_3$, $KNbO_3$, AND $PrAlO_3$

Participants: G. L. Catchen
E. F. Hollinger
M. C. Fonseca
J. M. Adams

Services Provided: Neutron Irradiation and Angular Correlations Lab

Perturbed-angular-correlation (PAC) spectroscopy was used to measure the temperature dependences of the nuclear-electric-quadrupole interactions at metal-ion-sites in ferroelectric, ternary-metal-oxide perovskites, $BaTiO_3$, $KNbO_3$, $PrAlO_3$. These compounds were prepared as ceramics doped with < 0.1 at. % Hf, which carried the ^{181}Hf --> ^{181}Ta PAC probe radioactivity. For $BaTiO_3$ and $KNbO_3$, the temperature dependences of the electric-field-gradient component V_{zz}, measured by the $^{181}Ta^{5+}$ probe ion at the Ti^{4+} and Nb^{5+} sites, respectively, are consistent with critical-exponent β values of approximately 0.3. Whereas, for $PrAlO_3$, V_{zz} decreases strictly linearly as temperature increases to the transition temperature T_c. This temperature dependence is unexpected and anomalous. We are investigating other rare-earth aluminates to obtain more information with which we can explain this anomaly.

Bachelor's Theses:

Hollinger, E. F., and G. L. Catchen, advisor. Perturbed-Angular-Correlation Spectroscopy: Rhombohedral-to-Cubic Transition in $PrAlO_3$. 1992

Fonseca, M. C., and G. L. Catchen, advisor. Perturbed-Angular-Correlation Spectroscopy: Tetragonal-to-Cubic Transition in $KNbO_3$. In progress.

Publication:

Adams, J. M. (presenter), G. L. Catchen, M. C. Fonseca and E. F. Hollinger. Using Nuclear-Electric-Quadrupole Interactions to Characterize Ferroelectric-to- Paraelectric Transitions in $BaTiO_3$, $KNbO_3$, and $PrAlO_3$. American Chemical Society National Meeting, Washington, DC. August 23-28, 1992.

Sponsor: Office of Naval Research $69,000

Nuclear Engineering

NEW TECHNIQUE TO DOPE GaAS CRYSTALS WITH THE $^{111}In \rightarrow ^{111}Cd$ PROBE FOR PERTURBED-ANGULAR-CORRELATION SPECTROSCOPY

Participants: G. L. Catchen
D. L. Miller
J. M. Adams
J. Fu

Services Provided: Angular Correlations Lab

Perturbed-angular-correlation (PAC) spectroscopy is an important technique for measuring defect and dopant interactions in group IV and III-V semiconductors. The probe of choice for most of the successful PAC experiments on semiconductors has been $^{111}In \rightarrow ^{111}Cd$ introduced by ion-implantation. Because facilities to implant radioactive ions such as ^{111}In have not been readily available in the U.S., we developed a simple closed-tube, vapor-phase-epitaxy (VPE) technique to produce ^{111}In-doped GaAs single-crystal epitaxial materials. PAC measurements on these crystals yielded essentially non-perturbed correlations that indicate that the ^{111}In probe was incorporated substitutionally into the GaAs crystals. These non-perturbed correlations differ significantly from the previously-reported weakly-perturbed correlations that were measured on GaAs crystals implanted with ^{111}In ions. Also an exploratory experiment using this VPE technique showed that Sn can be incorporated along with ^{111}In.

Publication:

Adams, J. M., J. Fu, G. L. Catchen and D. L. Miller. New Technique to Dope GaAs Crystals with the $^{111}In \rightarrow ^{111}Cd$ Probe for Perturbed-Angular-Correlation Spectroscopy. *Applied Physics Letters*. May 1992.

Paper:

Adams, J. M. (presenter), J. Fu, G. L. Catchen and D. L. Miller. New Technique to Dope GaAs Crystals with the $^{111}In \rightarrow ^{111}Cd$ PAC Probe. American Chemical Society National Meeting, Washington, DC. August 23-28, 1992.

Sponsor: National Science Foundation $60,000

Nuclear Engineering

TEMPERATURE DEPENDENCE OF THE Ti SITE ELECTRIC-FIELD GRADIENT IN TITANITE, $CaTiSiO_5$

Participants: G. L. Catchen
C. A. Randall
D. M. Spaar
S. J. Wukitch
J. M. Adams
R. L. Rasera

Services Provided: Neutron Irradiation and Angular Correlations Lab

Perturbed-Angular-Correlation (PAC) spectroscopy was used to measure nuclear-electric-quadrupole interactions at the Ti sites in ceramic samples of titanite. The primary objective was to measure the effects of the antiferroelectric-to-paraelectric transition, which occurs at approximately 500 K, on the electric-field gradients (efg) at the Ti site. The samples were doped with 2 and 0.5

at. % of Hf that carried the $^{181}Hf \rightarrow {}^{181}Ta$ PAC probes. Measurements were made over a temperature range from 10 to 980 K. Over the temperature range near the transition, the efg parameters V_{zz} and η showed no significant inflections. Over the entire temperature range, as temperatures increased, V_{zz} decreased approximately linearly and η remained relatively constant. Using the point-charge model, the absence of any discernable effect of the transition on the measured values of V_{zz} and η could be attributed to the direction and symmetry of the Ti-ion displacement relative to the Ti-site efg axes.

Publication:

Catchen, G. L., C. A. Randall and R. L. Rasera. Temperature Dependence of the Ti Site Electric-Field Gradient in Titanite $CaTiSiO_5$. *Physical Review B*, 45:5015-5018. 1992.

Nuclear Engineering

ORDER-DISORDER EFFECTS IN THE PHASE TRANSITIONS OF $LiNbO_3$ and $LiTaO_3$ MEASURED BY PERTURBED ANGULAR CORRELATION SPECTROSCOPY

Participants: G. L. Catchen
D. M. Spaar

Services Provided: Neutron Irradiation and Angular Correlations Lab

Perturbed-Angular-Correlation (PAC) spectroscopy was used to measure nuclear-electric-quadrupole interactions at the Li sites in two isostructural, ferroelectric ternary-metal-oxides, $LiNbO_3$ and $LiTaO_3$. These compounds were prepared as ceramics doped with approximately 0.01 at. % that carried the radioactive $^{181}Hf \rightarrow {}^{181}Ta$ PAC probes. PAC measurements were made over a temperature range from 295 K to ≈ 1100 K, which included the ferroelectric-to-paraelectric transition for $LiTaO_3$. Because the transition temperature T_c for $LiNbO_3$ exceeded the accessible temperature range of the available apparatus, the investigation focused mainly on the features of the $LiTaO_3$ transition. In particular, the measured perturbation functions show well-defined, high-frequency, static interactions that are characterized by extensive linebroadening at temperatures well below T_c and by significantly less linebroadening at temperatures above T_c. At temperatures above T_c, the electric-field-gradient (efg) asymmetry parameter η is close to zero; but at temperatures well below T_c, η is significantly larger than zero. This result is not expected, because the axial symmetry at the Li site associated with the diffraction-derived structure implies that h should vanish at temperatures both below and above T_c. The observed η temperature dependance is explained using an order-disorder model. This model suggests that Li Frenkel-pair defects (and to some extent group V antisite defects) occupy normally-vacant metal sites and break the axial symmetry associated with the Li site. At temperatures below T_c, the efg component V_{zz} increases as temperature increases. Distortion of the probe-containing oxygen octahedron that increases with temperature could produce this change in V_{zz}. Over the same temperature range, the spontaneous polarization decreases. For this reason, V_{zz} may not be strongly coupled to the order parameter for the transition. However, the anomalous temperature dependence of η suggests that η may be coupled to the order parameter.

Paper:

Catchen, G. L. Investigating Order-Disorder Effects in the Phase Transition of $LiNbO_3$ and $LiTaO_3$ Using Perturbed-Angular-Correlation (PAC) Spectroscopy. American Chemical Society National Meeting, Washington, DC. August 23-28, 1992.

Publication:

Catchen G. L., and D. M. Spaar. Order-Disorder Effects in the Phase Transitions of $LiNbO_3$ and $LiTaO_3$ Measured by Perturbed-Angular-Correlation Spectroscopy. *Physical Review B* 44:12137-12145. 1991.

Sponsor: Office of Naval Research $45,000

Nuclear Engineering

EXPLORATORY MEASUREMENTS OF COMBINED NUCLEAR-ELECTRIC-QUADRUPOLE AND MAGNETIC-HYPERFINE INTERACTIONS IN RARE-EARTH ORTHOFERRITES

Participants: G. L. Catchen
T. Rearick
J. M. Adams

Services Provided: Angular Correlations Lab

Perturbed-angular-correlation spectroscopy was used to measure nuclear-electric-quadrupole interactions and combined nuclear-magnetic-dipole interactions in nine of the rare-earth orthoferrites, $RFeO_3$ (R=La, Pr, Nd, ..., Lu). Ceramic samples were doped with trace amounts of $^{111}In/^{111}Cd$ PAC probes. Measurements were performed above and below the antiferromagnetic-to paramagnetic phase transition temperature, T_c. Above T_c, pure electric-quadrupole interactions were observed and the associated Fe-site electric-field gradients (efgs) were measured. Values for the efg parameters, V_{zz} and η, the line-shape parameter, δ, and the site-occupancy fraction, f_1, were obtained from the high-temperature perturbation functions. V_{zz} increases slowly with increasing atomic number of the rare-earth, and η decreases with increasing atomic number of the rare-earth and eventually vanishes for rare-earth orthoferrites containing rare-earths heavier than holmium. Also, V_{zz} decreases with increasing temperature; whereas, η, δ, and f_1 are all approximately constant. Interactions at a second site were also observed in most of the above-T_c perturbation functions, for which V_{zz}, η, δ, and f_2 were derived but not interpreted. Below T_c, the combined interaction was observed in all of the measured rare-earth orthoferrites. Frequencies obtained from the laboratory-temperature perturbation functions were used to estimate $y = (\omega_H/\omega_Q)$, the ratio of the magnetic-interaction frequency to the electric quadrupole interaction frequency, and β, the angle between the principal-axis of the efg tensor and the direction of the magnetic field for ^{111}Cd impurity ions at the Fe^{3+} sites. The ratio, y, is small (≤ 0.5) for these rare-earth orthoferrites, and the angle, β, is approximately 90°.

Bachelor's Thesis:

Rearick, T. M., and G. L. Catchen, advisor. Perturbed-Angular-Correlation Spectroscopy of Rare-Earth Orthoferrites. Engineering Science. 1992.

Paper:

Rearick, T. M. (presenter), G. L. Catchen and J. M. Adams. Combined Magnetic-Dipole and Electric-Quadrupole Hyperfine Interactions in Rare-Earth Orthoferrites. American Chemical Society National Meeting, Washington, DC. August 23-28, 1992.

Nuclear Engineering

TRITIUM CONTAMINATION OF METALS

Participants: W. S. Diethorn
A. R. Dulloo

Services Provided: Neutron Irradiation, Radiation Counters, Laboratory Space, Machine Shop, Isotope Production and Electronics Shop

Tritium contamination of equipment creates problems in waste control, radiological safety and tritium accountability at large tritium-processing facilities in the U.S. The purpose of this study is to investigate tritium distribution in materials of interest to the tritium-processing industry.

Recoil injection and diffusion-charging will be used to impregnate materials with tritium, and the tritium distribution resulting from these two methods of impregnation will be compared. The effects of factors such as grain size and sensitization on the tritium distribution will also be investigated.

Doctoral Thesis:

Dulloo, A. R., and W. S. Diethorn, advisor. An Experimental Study of the Distribution of Recoil- and Diffusion-Charged Tritium in Metals. In progress.

Sponsor: EG&G Mound Applied Technologies, fourth year

Nuclear Engineering

UNDERGRADUATE LABORATORY ON REACTOR EXPERIMENTS

Participants: R. M. Edwards
M. A. Power
M. E. Bryan
D. E. Hughes

Services Provided: Laboratory Space, Machine Shop, Electronics Shop, Reactor Instrumentation and Support Staff

The Nuclear Engineering 451 course is the second of two required 3 credit laboratory courses. Each weekly laboratory exercise usually consists of 2 lectures and one laboratory session conducted. The first course (NucE 450) covers radiation instrumentation and measurement and is conducted in the 2nd semester of the junior year. By the beginning of the senior year, the students have already covered the LaMarsh reactor theory book including reactor point kinetics. The 451 course then emphasizes experiments using the instrumentation that was covered in the first course and is divided into two (more or less) equal "tracks". These tracks can be coarsely described as TRIGA and non-TRIGA experiments and each is the major responsibility of a different professor. The non-TRIGA track includes 3 graphite pile, 2 analog simulation, and 1 power plant measurement experiment.

In 1991, the TRIGA track included:

1. Digital Simulation of TRIGA Reactor Dynamics
2. Control Rod Calibration
3. Large Reactivity Insertion (Pulsing)
4. Reactor Frequency Response
5. Neutron Noise
6. Reactor Control

This 1991 sequence was only a slight modification over the previous course organization of recent years. The reactor control experiment replaced a reactor gamma field measurement experiment and the digital simulation exercise was modified to point kinetics from its previous focus on Xenon dynamics. Reactor control is offered as a graduate course in our department but until now our undergraduates have not received a complete introduction to feedback control.

In 1991, 5 MacIntosh Computers equipped with GW Electronics MacAdios and Superscope software became available for conducting TRIGA reactor experiment data collection and analysis. The goal for utilizing this computer equipment is to give students more hands-on experience in setting-up the data collection and conducting the TRIGA experiments. The MacIntosh computers were used to conduct and monitor the reactor control experiment and were used in monitoring the reactor frequency response and large reactivity insertion experiments. They are also adaptable for the other experiments and work will continue to fully utilize them for this purpose.

Publication:

Edwards, R. M., M. A. Power and M.E. Bryan. An Undergraduate Reactor Control Experiment. *ANS Transactions*. June 1992.

Nuclear Engineering

NUCE 505 REACTOR CONTROL

Participants: R. M. Edwards
M. A. Power
M. E. Bryan
D. E. Hughes

Services Provided: Laboratory Space, Machine Shop, Electronics Shop, Reactor Instrumentation and Support Staff

One laboratory to demonstrate reactor control was conducted for the graduate Reactor Control course, NucE 505.

Nuclear Engineering

ROBUST OPTIMAL CONTROL OF TRIGA REACTOR TEMPERATURE

Participants: R. M. Edwards
M. A. Power
J. A. Turso
D. E. Hughes
M. E. Bryan

Services Provided: Laboratory Space, Machine Shop, Electronics Shop, Reactor Instrumentation and Support Staff

Based on a prototype TRIGA Reactor Optimal Control experiment conducted during the summer of 1991, this area has been expanded into a full range of experiments to verify the robustness characteristics of this optimal control application. This is a FERMI funded project to be completed by the end of 1992 and will provide useful background material for future research proposals.

A Bailey NETWORK 90 Distributed Control System is used to implement the optimal control algorithm which is implemented in the Bailey controller using general purpose C language programming. The Bailey drives the Secondary Control Rod (SCR) drive which travels in the central thimble while the licensed control and safety system is in a manual mode of operation. The

Bailey System at the reactor was augmented with a Computer Interface Unit which enables utilization of standard Bailey Software for generating displays of process information.

Advanced control algorithms, such as this optimal control algorithm, require some kind of dynamic model of the process in order to achieve improved performance characteristics. The concept of robustness is how far can the actual process deviate from the *assumed* process model and still maintain required stability and desired performance improvement. Through extensive simulation, this optimal controller which is based on a one-delayed neutron group model, has been shown to maintain desired performance for a factor of 10 variation in the power level and control rod worth for which it was designed. The current experimental program is to verify these simulation predictions.

Master's Thesis:

Power, M. A., and R. M. Edwards, advisor. Experiment Verification of Robust Optimum Control for Improving Reactor Temperature Response. In progress.

Papers:

Edwards, R. M., C. K. Weng and R. W. Lindsay. Experimental Development of Power Reactor Advanced Controllers. Presented at The Eight Power Plant Dynamics, Control & Testing Symposium, Knoxville, TN. May 27-29, 1992.

Turso, J. A., R. M. Edwards, D. Hughes, M. Bryan and H. E. Garcia. Experience with Developing a Real-World Advanced Control and Diagnostic Testbed Using a University Research Reactor. *AI 91: Frontiers in Innovative Computing for the Nuclear Industry*. Vol 1:889-898. American Nuclear Society Meeting at Jackson, WY. September 15-17, 1991.

Edwards, R. M., H. E. Garcia, J. A. Turso, C. M. Chavez, A. BenAbdennour, C. K. Weng, C. C. Ku, A. Ray and K. Y. Lee. Advanced Control Research at Penn State. EPRI meeting on Advanced Digital Computers, Controls, and Automation Technologies for Power Plants, San Diego, CA. February 5-7, 1992.

Publications:

Edwards, R. M., J. A. Turso, K. Y. Lee, H. E. Garcia and A. Ray. The Penn State Intelligent Distributed Control Research Laboratory. IEEE Power Engineering Society Winter Meeting. #92 WM 075-2-EC and accepted for publication in *IEEE Transactions on Energy Conversion*. January 1992.

Turso, J. A., R. M. Edwards, D. Hughes, M. Bryan and H. E. Garcia. Experience with Developing a Real-World Advanced Control and Diagnostic Testbed Using a University Research Reactor. *AI 91: Frontiers in Innovative Computing for the Nuclear Industry*. Vol 1:889-898. American Nuclear Society Meeting at Jackson, WY. September 15-17, 1991.

Kenney, E. S., R. M. Edwards, K. Y. Lee, A. Ray and S. T. Kumara. Final Technical Report: Engineering Research Equipment Grant-Microprocessor-Based Controllers. NSF Grant ECS-8905917. January 1991.

Sponsor: FERMI $12,000

Nuclear Engineering

CHROMATOGRAPHIC SYSTEM FOR RADIOISOTOPE ANALYSIS

Participants: W. A. Jester
A. R. Dulloo
C. D. Bliestein

Services Provided: Neutron Irradiation, Radiation Counters, Laboratory Space, Machine Shop, Isotope Production, Electronics Shop and Ion Chromatographic System

The analysis of aqueous emissions from nuclear power plants prior to release to the environment is an area of importance to the nuclear industry. It is difficult to detect and quantify the activities of certain radionuclides present in the emissions due to interference from the activities of other radionuclides. Chemical separation methods are necessary to isolate these nuclides before detection. Unfortunately, these chemical methods are expensive, time-consuming, and are often performed offsite by commercial laboratories.

The purpose of this study is to develop a system which would allow for the automated separation of the radionuclides in an aqueous mixture using high performance liquid chromatography, followed by the detection and measurement of separated nuclides of interest with a radiation detector. Such a system would permit the onsite analysis of aqueous effluents from nuclear power plants without the need for costly and time-intensive chemical separation methods. Most plants already have high performance chromatography equipment used to perform chemical analysis of water samples.

Publications:

Jester, W. A. Use of Neutron Activation Tracers for Studying the Chromatographic Separation of Strontium and Yttrium. Trans. of American Nuclear Society. TANSAO 641-754 Vol. 64:234-235. 1991.

Bliestein, C. D., and W. A. Jester. Chromatographic System for Radioisotope Analysis. Interim reports submitted to Ben Franklin Partnership Program. September 1, 1991 to November 30, 1991 and December 1, 1991 to February 29, 1992.

Sponsor: Ben Franklin Partnership Program with matching funds from CB-Tech and Penn State University - Total $141,733

Nuclear Engineering

STUDY OF THE DEPOSITION LOSSES OF AIRBORNE RADIOIODINE SPECIES IN SAMPLE LINES UNDER NORMAL AND ACCIDENT CONDITIONS OF NUCLEAR POWER PLANTS

Participants: W. A. Jester
B. S. Lee

Services Provided: Neutron Irradiation, Radiation Counters, Laboratory Space, Machine Shop, Isotope Production and Electronics Shop

Airborne radioiodine species either in gaseous or particulate forms can be lost inside sample lines used in nuclear power plants. The deposition losses of these radioiodine species can make a bias in the measured iodine activity collected in monitor filters installed at the end of the long sample lines. Currently available experimental data do not agree with each other and no models exist to explain the experimental results. Most of the experimental works are black-box approach,

knowing only input and output amount of radioiodine. To better understand mechanisms involved in the radioiodine deposition in the sample lines, experiments using short half-lived ^{128}I radioisotope (either I_2 or Ch_3I or particluate iodines) have been conducted on the type 316 stainless steel sample lines. The deposition profiles of these radioiodine species were obtained using a thin Geiger tube along the length of the line for various test conditions.

Doctoral Thesis:

Lee, B. S., and W. A. Jester, advisor. Study of the Deposition Losses of Airborne Radioiodine Species in Sample Lines Under Normal and Accident Conditions of Nuclear Power Plants. In progress.

Publications:

Lee, B. S., W. A. Jester and J. M. Olynyk. Radioiodine Specialization in the Hot Cell Effluent ... of a Radiopharmaceutical Producation Facility. *Health Physics*, 61(2):255-258. 1991.

... W. A. Jester and J. M. Olynyk. On-Line Radioiodine Measurement Using Hot Cell ... nt Gases of a Radiopharmaceutical Production Facility. *Nuclear Technology* , 97:63-70.

... W. A., T. T. Tseng and B. S. Lee. Radioiodine Monitoring of Nuclear Power Plant ... oorne Emissions Under Accident Conditions. Accepted for publication in the proceedings of the Seventh ASTM-EURATOM Symposium on Reactor Dosimetry.

Sponsor: FERMI $17,068

Nuclear Engineering

ENVIRONMENTAL BACKGROUND MONITORING USING ELECTRET PASSIVE ENVIRONMENTAL MONITORS

Participants: W. A. Jester

Services Provided: Radiation Counters, Laboratory Space and Low Level Monitoring Lab

Rad-Elect Electret passive environmental monitors are a new type of monitor for the detection of gamma environmental radiation. For the past three years, quarterly measurements have been taken at ten positions in and near the Radiation Science Center. At the same time and locations, the university Health Physics staff has been making TLD measurements of the gamma background. Results obtained from these two different methods of background measurements are then compared.

Sponsor: Equipment donated by Rad-Elec $3,000

Nuclear Engineering

THE DEVELOPMENT OF A CARBON-14 AND TRITIUM GASEOUS EFFICIENT MONITOR

Participants: W. A. Jester
K. M. Alam

Services Provided: Laboratory Space, Machine Shop Low Level Monitoring Lab and Electronics Shop

This research project is based upon the collection of carbon dioxide and water vapor from air using molecular sieves. Later on, the species mentioned above are desorbed by heating. The activities of carbon-14 and tritium contained in the species collected are determined using liquid scintillation counting.

The system was built in the facility machine shop and calibrated in the laboratory. The experiments were performed in a hood with the exhaust fan turned on. A typical experiment involved the absorption of 111 nCi of carbon-14 and 16 nCi of tritiated water on approximately 100 g of molecular sieves. Later on the sieves were heated to 825°F. Desorbed tritiated water was collected in a biodegradable organic scintillator, ecoscint. Carbon-14 was collected in a mixture of CO_2-absorber (carbamate) and the organic scintillator. Currently, the development and testing of the final system has been completed and it has been used to monitor airborne tritium and carbon-14 at the Radiation Science and Engineering Center.

Doctoral Thesis:

Alam, K. M., and W. A. Jester, advisor. Development of Carbon-14 and Tritium Gaseous Effluent Sampler for Nuclear Power Plants. In progress.

Publication:

Alam, K. M., and W. A. Jester, advisor. Development of Carbon-14 and Tritium Gaseous Effluent Monitor. *Trans. of American Nuclear Society*. June 1992.

Sponsor:		
	Project FERMI	$15,000
	Pennsylvania Power & Light	$25,000

Nuclear Engineering

VERIFICATION OF LITHIUM-7 ENRICHMENT IN LITHIUM HYDROXIDE BY THERMAL NEUTRON IRRADIATION

Participants: W. A. Jester
A. R. Dulloo

Services Provided: Neutron Irradiation, Radiation Counters, Laboratory Space, Isotope Production and Low Level Monitoring Lab

Lithium hydroxide (LiOH) is used to control the pH of coolant water in the primary loop of pressurized water reactors. Natural lithium consists of 93.45 w/o ^{7}Li and 6.55 w/o ^{6}Li. Because of the high thermal neutron cross section of the $^{6}Li(n,\alpha)^{3}H$ reaction, it is desirable to use a lithium compound enriched in the ^{7}Li isotope to minimize the production of radioactive tritium (^{3}H). ^{7}Li has a zero thermal neutron reaction cross section for ^{3}H formation, and lithium hydroxide compounds used in PWRs are typically enriched to 99.9 w/o ^{7}Li.

A simple method to measure the ^{7}Li content of an enriched LiOH compound has been developed. Enriched LiOH is irradiated in a thermal neutron flux, and its resulting ^{3}H activity is radioassayed and compared to that of natural LiOH which has been subjected to an identical irradiation. Since the ^{3}H activity is a linear function of the ^{7}Li amount in the compound, the percentage of ^{7}Li in the enriched compound can be calculated based on the well-known concentration of ^{7}Li in natural lithium. This method has been used to compare the ^{7}Li contents of several enriched LiOH powders sold by different vendors, and will be available to commercial customers by the facilities of the Low Level Radiation Monitoring Laboratory.

W. A. JESTER'S PAPERS AND PUBLICATIONS FROM PREVIOUS WORK AT THE REACTOR NOT INCLUDED IN LAST YEAR'S REPORT

Jester, W. A., and D. C. Raupach. Neutron Activation Analysis Instruction at Pennsylvania State University. *Trans. of American Nuclear Society*. TANSAO 641-754, 64:225. 1991.

Okyere, E. W., A. J. Baratta and W. A. Jester. The Response of Ex-Core Neutron Detectors to Large-and Small-Break Loss-of-Coolant Accident in Pressurized Water Reactors. *Nuclear Technology*. 96:272-289. 1991.

Gundy, L. M., A. J. Baratta, G. R. Imel and W. A. Jester. Analysis of Ex-Core Neutron Detector Response During a Loss-of-Coolant Accident. *Nuclear Technology*. 94:297-312. 1991.

Nuclear Engineering

UPGRADING THE EQUIPMENT FOR NUCE 450 AND 451 NUCLEAR ENGINEERING LABORATORY COURSES

Participants: W. A. Jester
E. S. Kenney
M. L. Voth
R. M. Edwards

Services Provided: Neutron Irradiation, Gamma Irradiation, Hot Cell Lab, Radiation Counters and Laboratory Space

Four new Macintosh II computer plus interfaces and software have been purchased to provide individual stations for students performing NucE 451 reactor experiments at the Radiation Science and Engineering Center. Three new ion chambers were also purchased for this purpose. In addition, a software package has been developed to assist NucE students to write lab reports for NucE 450 and 451. This program package is made available to students on these four new Macintosh computers at the Radiation Science and Engineering Center, and on Macintosh computers located in the department's computer laboratory at Sackett Building.

Sponsors:

Ben Franklin Equipment Grant matching university funds	$47,000
Software developed under a faculty technology initiative program of Penn State's - BEL-Teaching and Learning Technologies groups with funds from Nuclear Engineering and the College of Engineering	$20,000

DEVELOPMENT OF A SOURCE HOLDER AND CONVERSION TABLES FOR USE WITH EBERLINE RO-2'S TO ALLOW THE MEASUREMENT OF THE SKIN DOSE RATES FROM BETA-GAMMA SOURCES

Participants: W. A. Jester
S. H. Levine
M. Chung
T. J. Lin

Services Provided: Radiation Counters, Laboratory Space, Machine Shop, Isotope Production, Low Level Monitoring Lab and Electronics Shop

In this project, techniques are being developed to determine skin dose rates from beta-gamma sources using an Eberline RO-2 ion chamber. A program called E13RO2 has been modified from the ZEBRA code (a Monte Carlo program developed by Martin J. Berger) for use in computing the beta dose from an RO-2 measurement. The E13RO2 program is a two dimensional program written in Turbo Basic and can be run on an IBM compatible microcomputer. It calculates the energy deposited in the detector air volume and computes beta skin dose rates as a function of source type, source strength, source diameter, source-detector distances and shield between source and chamber. To fit the RO-2, the geometrical factors of that detector have been taken into consideration.

A table is being developed to evaluate the skin dose from RO-2 outputs as a function of the measured dose ratio, which is the ratio of outputs obtained without and with a gradient shield of 7 mg/cm^2 mass thickness, various source radii and source-detector distances.

A source holder for the RO-2 chamber has been designed and finished to hold any kind of beta-gamma source at a fixed source-detector distance. The holder has been used to measure many different sources to generate the conversion tables in cooperation with the E13RO2 program. Measurements using ^{60}Co, ^{204}Tl, ^{147}Pm, and $^{90}Sr/^{90}Y$ sources under different conditions show good agreement with E13RO2 calculations.

Master's Thesis:

Lin, T. J., and W. A. Jester, advisor. Development of a Beta Skin Dose Monitor Using an Eberline RO-2 Portable Ion Chamber. In progress.

Publication:

Jester, W. A., and S. H. Levine. The Development of a Source Holder and Conversion Factor Graphs for Use with Eberline RO-2's to Allow the Measurement of Contact Dose Rates From Small Beta-Gamma Sources. Progress report submitted to PP&L, 13 pages. August 1991.

Sponsor: Pennsylvania Power and Light Company $52,766

DEVELOPMENT OF A BETA SKIN DOSE MONITOR USING SILICON DETECTORS

Participants: W. A. Jester
S. H. Levine
M. Chung

Services Provided: Radiation Counters, Laboratory Space, Machine Shop, Isotope Production, Low Level Monitoring Lab and Electronic Shop

The purpose of the research is to develop improved ways to calculate and measure the beta skin dose. The one-dimensional Monte Carlo electron transport code, ZEBRA, was converted to Eltran2 and Eltran3 for use on the Macintosh or any IBM compatible microcomputer. Of the various types of detectors, the semiconductor detector was chosen, because it has small size and high sensitivity. Especially, a low leakage current ion-implanted silicon detector was selected for this research. To cover a wide range of dose rate, both the pulse and current mode operations of the silicon detector were used, with an overlap of one order of magnitude in the measurable dose rate ranges in the two modes. By using a shield of 7 mg/cm^2 on the silicon detector, dose gradient measurements were performed. Based on this research, a prototype beta skin dose monitor has been constructed, including an A/D convertor and a microprocessor with a machine coded program to calculate the skin dose. It covers more than five orders of magnitude in the measurable beta dose rate ranges. The prototype device has been field tested at the TMI nuclear plant site with hot particles and various other radioactive sources. Nuclear Research Corporation is building a commercial monitor based on this work.

Doctoral Thesis:

Chung, M., W. A. Jester and S. H. Levine, advisors. Research and Development of a Beta Skin Dose Monitor Using Silicon Detectors. 1991.

Publications:

Chung, M., A. H. Foderaro, W. A. Jester and S. H. Levine. Microcomputer Monte Carlo Electron Transport Codes for Beta Skin Dose Calculations. *IEEE Trans. Nuclear Science* 38(3):936-991. 1991.

Chung, M., W. A. Jester and S. H. Levine. Development of a Beta Skin Dose Monitor Using a Silicon Detector. *IEEE Trans. Nuclear Science* 38(4):964-970. 1991.

Chung, M., W. A. Jester and S. H. Levine. Monte Carlo Calculations and Silicon Detector Measurements of the Hot Particle Dose. *Health Physics*. 61(6)843-848. 1991.

Jester, W. A., S. H. Levine, M. Chung, T. Y. Lin and J. W. Schmidt. A Field Test of Prototype Beta Skin Dose Monitor. Submitted to Project FERMI, 24 pages. May 1991.

Sponsors:

FERMI	$22,326
Duquesne Light Company	$25,000
GPU Nuclear Corporation	$15,000

Nuclear Engineering

DEVELOPMENT OF A COMMERCIAL BETA SKIN DOSE MONITOR

Participants: W. A. Jester
S. H. Levine
T. J. Lin
M. Chung

Services Provided: Laboratory Space, Machine Shop, Low Level Monitoring Lab and Electronics Shop

This project is an extension of our previous work on the development of a beta skin dose monitor. Nuclear Research Corporation in cooperation with Dr. Jester and Dr. Levine are developing a commercial version of one of the concepts proposed and evaluated by Manho Chung during his Ph.D. thesis work. In this concept the beta dose response of a silicon detector as a function of applied voltage is used to determine the beta skin dose. The magnitude of the reverse bias voltage determines the thickness of the dead layer between the beta source and the sensitive volume of the silicon detector. This layer can be used to approximate the dead layer thickness of the skin.

Publication:

Jester, W. A. and S. Pandy. Development of a Commercial Beta Dose Monitor. Interim reports submitted to Ben Franklin Partnership Program. September 1, 1991 - November 30, 1991 and December 1, 1991 - February 24, 1992.

Sponsor: Nuclear Research Corporation and Ben Franklin Partnership Program $74,027

Nuclear Engineering

PIPE WALL THINNING USING SCATTERED GAMMA RAYS

Participants: E. S. Kenney
X. Xu

Services Provided: Hot Cell Lab, Radiation Counters, Laboratory Space, Machine Shop, Isotope Production and Electronics Shop

Pipe wall thinning continues to be a serious problem in the nuclear industry. The problem first appeared in PWRs, but is now recognized throughout the industry. This project has demonstrated that pipe wall thinning can be detected using scattered gamma rays. A combination of Monte Carlo studies and pilot experiments have confirmed the potential of such a technique. We have a laboratory prototype gauge working using up to 0.5 curies of Ir-192 and are now designing a field usable device.

Master's Thesis:

Xu, Xiangjun, and E. S. Kenney, advisor. A High Speed Wide-Aperture Compton Scatter NDT Gauge Using a Multi-Energy Source. In progress.

Sponsor: FERMI $30,000

Nuclear Engineering

NEUTRON ATTENUATION MEASUREMENTS OF BORAFLEX

Participants: D. Kline
D. Vonada
K. Lindquist

Services Provided: Neutron Irradiation, Neutron Instrumentation and Beam Lab

The purpose of this project is to measure the neutron attenuation of boraflex coupons that have been taken from fuel storage racks. It is a part of a larger project to assure the integrity of the boraflex which maintained the low Keff of the storage pool. The attenuation measurements are made by using a fission chamber instrument to compare the incident beam with the transmitted beam.

Nuclear Engineering

PPOPERTIES OF THE NEUTRON ABSORBER MATERIAL BORAFLEX

Participants: D. Kline
D. Vonada
K. Lindquist

Services Provided: Neutron Irradiation and Laboratory Space

Boraflex is a composite polymer of polysiloxanes with a B4C-filler used in maximum-density storage of fuel elements to control the reactivity. Boraflex performance has deteriorated after some years of use, but somewhat before the anticipated service life of the high-density.

Data from the literature concerning polydimethylsiloxane were evaluated a few years ago, and Boraflex coupon monitoring is currently being carried out at storage pool sites. It is also of academic interest to study some of the properties of the polymer using the nuclear reactor (PSBR), and other facilities.

It is hoped that results can be obtained to explain certain aspects of the changes in properties, and that they can be used by utilities throughout Pennsylvania and the United States in estimating and/or extending the service life of the B4C-filled polymer system.

An additional phase involves ascertaining property changes of in-service Boraflex. About once per year a surveillance coupon from a storage pool is sent to PSU and evaluated for radiation-induced changes. Fractions of deteriorated Boraflex with a substantial irradiation history are also monitored for possible post-irradiation deterioration in water baths held at controlled conditions.

Nuclear Engineering

MECHANICAL PROPERTIES OF BORATED STAINLESS STEEL TO BE USED IN SPENT FUEL RACK ASSEMBLIES

Participants: M. P. Manahan
J. He
A. J. Baratta

Services Provided: Neutron Irradiation, Hot Cell Lab, Radiation Counters, Machine Shop, Low Level Monitoring Lab and Electronic Shop

The purpose of this project is to perform test and analysis of the mechanical properties of several types of borated stainless steels manufactured by Carpenter Technology Corporation. Test specimens in either neutron irradiated or unirradiated conditions will be tested to investigate potential effects of neutron irradiation on the mechanical properties of borated steels. The main application of these steels is to make spent fuel storage channel boxes. It is a concern that neutron irradiation embrittles material. In addition, borated steels contain boron which is a strong neutron absorber and produces helium upon reaction with a neutron. Helium is believed to assist void growth. So the exact effect of neutron irradiation on the mechanical properties of borated stainless steels is both fundamentally interesting and practically important. Our study will answer most of these concerns and present corresponding recommendations for the intended applications.

Our project includes testing of life-size channel boxes by compressing both unirradiated and irradiated channel boxes along the sample lateral, diagonal or axial (along one corner) direction. The most important part of the project includes testing of tensile samples and compact tension samples (for JIc fracture toughness) in conditions of a combination of various temperatures and neutron irradiation fluences. Currently, neutron irradiation of all the test samples is complete. Channel box testings are also complete. Tensile testing calibration and JIc testing calibration are complete. Tensile testings are half way towards completion. In addition, a relatively complete and thorough dosimetry analysis of neutron fluxes on the specimen irradiation locations is underway to give a better correlation of neutron irradiation fluence and the specimen mechanical property changes. We expect the investigation to be completed by the end of the year.

Sponsor: Carpenter Technology

Nuclear Engineering

RECONSTITUTION OF BROKEN CHARPY SPECIMENS USING LASER WELDING

Participants: M. P. Manahan
J. F. Williams
R. P. Martukanitz
R. L. Eaken

Services Provided: Hot Cell Lab, Laboratory Space and Machine Shop

As nuclear power plants approach end-of-license (EOL) and consideration is given to license renewal, there is an ever increasing need to expand the amount of obtainable data from the original power plant surveillance specimens. A laser welding technique to reconstitute broken Charpy specimens is being developed and applied to conventional Charpy specimens.

In order to benchmark the laser weld procedure, the laser reconstituted specimen data are compared with the original specimen data. In addition, the microstructure after welding must be examined to ensure that the material in the vicinity of the notch is essentially unchanged after the welding process. Data which characterize the thermal transients during welding is obtained by attaching

thermocouples to the specimens. These data are compared with transient thermal calculations. Precise control of welding parameters has been demonstrated, heat affected zones are small, and sufficient penetration depth can be obtained to enable welding thick specimens to yield conventionally Charpy specimens. Given the range of controllable variables, it is likely that future work will lead to an optimized procedure which results in the minimum use of valuable irradiated material.

Master's Thesis:

Williams, J. F. and M. P. Manahan, advisor. Reconstitution of Broken Charpy Specimens Using Laser Welding. In progress.

Paper:

Williams, J. F., M. P. Manahan and R. P. Martukanitz. Laser Weld Reconstitution of Conventional Charpy and Miniaturized Notch Test (MNT) Specimens. Talk at the ANS Regional Conference, University of Michigan. April 1992. (Same presentation to FERMI group.)

Sponsor: FERMI

Nuclear Engineering

NINE MILE POINT UNIT 1 STRESS CORROSION CRACKING SENSOR POST-IRRADIATION EXAMINATION

Participants: M. P. Manahan
T. K. Yeh

Services Provided: Hot Cell Lab, Machine Shop and Electronics Shop

The stress corrosion monitors which had been irradiated for one and a half years at Nine Mile Point Unit 1 nuclear power plant will be shipped to PSU and investigated in the Hot Cell laboratory. The main objective of this experiment is to find the stress corrosion cracking characteristics of annealed and sensitized 304 stainless steels. Both non-destructive and destructive tests will be performed.

All the specimens are in the shape of a double cantilever beam. Therefore, H. Tada's simple beam theory is employed to calculate all the needed parameters such as stress intensity at crack root, crack opening displacement, bending stress, etc. The preparation work in the hot cell for receiving the irradiated specimens is nearly done.

Sponsor: Niagara Mohawk Power Corporation

Nuclear Engineering

EVALUATING TWO PHASE FLOW WITH NEUTRON RADIOGRAPHY

Participants: D. E. Hughes
S. S. Glickstein
R. Gould

Services Provided: Neutron Radiography, Machine Shop and Flux Monitoring

This project is the evaluation of the void fraction between two plates as a function of flow and heat production. Neutron radiography imaging is being used to make the evaluation. The project is still in the initial phase but is continuing.

Publication:

Glickstein, S. S., J. Joo and W. H. Vance. Interpreting Neutron Radiographics Via Computer Simulation, Bettis Atomic Power Laboratory. Presented at Fourth World Conference on Neutron Radiography, San Francisco, CA. May 10-16, 1992.

Sponsor: Bettis Atomic Power Laboratory

Nuclear Engineering

TRACE ELEMENT ANALYSES OF QUARRY ROCK SAMPLES

Participants: D. C. Raupach
F. J. Vento

Services Provided: Radiation Counters and Isotope Production

Seventeen rock samples were sent to the Breazeale Nuclear Reactor facility for trace element analysis using neutron activation analysis.

Sample preparation and encapsulation were performed by the radionuclear applications laboratory personnel. The samples were irradiated, counted, and quantitative analyses of the elements present in the rock samples were performed.

Of prime interest was the presence or absence of rare earth elements in the samples, and if present, what was the relative concentration in each sample.

The objective of the test was to see if a elemental "fingerprint" could be gotten for samples from different quarry locations.

Nuclear Engineering

TRACE ELEMENT ANALYSES OF SAMPLES FROM AN ARCHAEOLOGICAL DIG SITE

Participants: D. C. Raupach
M. Moore

Services Provided: Radiation Counters and Isotope Production

Samples from an archaeological dig site in southeastern Maryland were sent to the RSEC for analyses. The tests, using neutron activation analysis, were to help determine if samples within each group could be identified as having come from a common source by comparing the quantity of trace elements present in the samples.

Nuclear Engineering

TRACE ANALYSIS FOR ELEMENT CONTAMINANTS

Participants: D. C. Raupach
M. McClain

Services Provided: Radiation Counters and Isotope Production

A sample of AQUAZOL was analyzed by the radionuclear application laboratory personnel to see if they could identify trace element contaminants in the sample.

The sample was analyzed using the neutron activation analysis technique. Trace amounts of five different elements were found in the sample.

Nuclear Engineering

AUTOMATED THERMAL POWER CALIBRATION TECHNIQUE FOR THE TRIGA REACTOR

Participants: M. H. Voth
K. Sahadewan
D. E. Hughes
M. E. Bryan

Services Provided: Neutron Irradiation, Laboratory Space, Machine Shop and Electronics Shop

Thermal power calibrations are routinely performed at the Penn State TRIGA reactor to establish a reproducible relationship between actual and indicated power after changes in core loading, instrument repositioning and fuel burnup.

The new calibration technique, which was incorporated as one of Penn State TRIGA Reactor's Calibrations and Checks Procedure (CCP-2), improves upon the accuracy, sensitivity, and reproducibility of the previous method. The new technique isolates the core and keeps the pool temperature constant by controlling flow through the heat exchanger. By keeping the pool temperature constant, heat losses due to convection and conduction are minimized and kept nearly constant.

Temperature readings are monitored using two-terminal IC temperature transducers. The flow rate through the primary side of the heat exchanger is measured by a magnetic flow sensor. In an ideal environment, the heat rejected by the heat exchanger plus the calculated heat loss terms will equal heat generated by the core.

Sensitivity studies reveal that the greatest source of error in the determination of thermal power is introduced by uncertainties in the measurement of flow rate and temperature. The magnetic flowmeter readings are accurate to within ± 0.5% of reading plus within ± 0.05% of full scale, and the temperature transducers are sensitive to ± 0.01 °C. Error analysis shows that with these instruments the thermal power can be measured with an uncertainty of ± 2%.

Master's Thesis:

Sahadewan, K., and M. H. Voth, advisor. Automated Thermal Power Calibration Technique for the TRIGA Reactor. 1992.

B. OTHER UNIVERSITIES' AND INDUSTRIAL RESEARCH UTILIZING THE FACILITIES OF THE RADIATION SCIENCE AND ENGINEERING CENTER

University or Industry	Type of Use
Alliant Tech Systems	Semiconductor Irradiation
Armed Forces Radiobiology Research Institute	Neutron Radiography
	Neutron Activation Analysis
Army Pulsed Reactor Facility, Aberdeen	Neutron Energy Spectrum Analyses
Bettis Labs	Neutron Radiography
Carpenter Technology	Neutron Radiography
CB-Tech	Neutron Activation Analyses
Clarion University, Geology Department	Neutron Activation Analyses
David Sarnoff Research Center	Semiconductor Irradiation
Eagle Pitcher	Neutron Irradiation
Emanco, Inc.	Neutron Activation Analyses
E-Systems	Semiconductor Irradiation
Fairway Laboratories	Environmental Analyses
GEC-Marconi	Semiconductor Irradiation
Geochemical Testing	Environmental Analyses
Harris Semiconductor	Semiconductor Irradiation
Hrebeniuk, Alex - Horticulturist	Gamma Irradiation
Honeywell	Semiconductor Irradiation
Kearfott, Inc.	Semiconductor Irradiation
Kobe University, Japan	Neutron Radiography
Mine Safety Appliance Company	Neutron Radiography
National Sanitation Foundation	Environmental Analyses
Niagara Mohawk	Neutron Radiography
North Carolina State University, Chemistry Dept.	Cobalt Irradiation
Northeast Technology Corporation	Neutron Radiography
P. R. Hoffman Materials Processing Corp.	Cobalt Irradiation
Penn State Fayette Campus	Cobalt Irradiation
Polymer Chemistry Innovations	Neutron Activation Analyses
Q. C. Inc.	Environmental Analyses
Raytheon	Semiconductor Irradiation
Sandia National Laboratory	Neutron Energy Spectrum Analyses
Seewald Laboratories	Environmental Analyses
Tru-Tech	Isotopes for Tracer Studies
University of Maryland	Perturbed Angular Correlation

APPENDIX A

APPENDIX A

Personnel Utilizing the Facilities of the Penn State RSEC.
Faculty (F), Staff (S), Graduate Student (G), Undergraduate (U)

COLLEGE OF AGRICULTURE

Dairy and Animal Science

Killian, Gary (F)
Zaczek, Denise (S)

Entomology

Hower, Art (F)

Food Science

Beelman, Robert (F)
Kim, Jeong-Weon (G)
Poores, Stephanie (F)

Northeast Watershed Research Center

Schnabel, Ron (S)

Plant Pathology

Juba, Jean (S)
Klotz, Lois V. (S)
Nelson, Paul E. (F)
Romaine, Peter (F)

COLLEGE OF EARTH & MINERAL SCIENCES

Geosciences

Daub, Gary (U)
Eggler, Dave (F)
Shank, Steve (G)
Kump, Lee (F)

Metals Science and Engineering

Freyer, Paula (G)
Martukanitz, Richard (G)
Pickering, H. (F)

COLLEGE OF ENGINEERING

Engineering Science and Mechanics

Gabrys, Jon (U)
Lenahan, Patrick (F)
Rose, Joseph (F)
Tittman, B. R. (F)
Yount, James (G)

Industrial Engineering

Poeth, Dean (G)
Ruud, Clayton (F)

Mechanical Engineering

Cimbala, John (F)
Sathianathan, Dhushy (F)

Nuclear Engineering

Adams, James (G)
Alam, Khalid (G)
Baratta, Anthony (F)
Bernold, Matthew (U)
Boyle, Hermina (S)
Boyle, Patrick (S)
Bryan, Mac (S)
Catchen, Gary (F)
Chung, Manho (G)
Davison, Candace (S)
Deithorn, Ward (F)
Dulloo, Abdul (G)
Edwards, Robert (F)
Flinchbaugh, Terry (S)
Fonseca, Marie (U)
Hanna, R. J. III (U)
Hannold, Eric (S)
Hollinger, Ed (U)
Hughes, Dan (F)
He, Jianhui (G)
Jester, William (F)

APPENDIX A
(Continued)

Personnel Utilizing the Facilities of the Penn State RSEC.
Faculty (F), Staff (S), Graduate Student (G), Undergraduate (U)

Nuclear Engineering

Kenney, Edward (F)
Lee, Byung-Soo (G)
Levine, Samuel (F)
Lin, Tzyy-Jye (G)
Lu, Jianhui (G)
Lu, Shanli (G)
Manahan, Michael (F)
Power, Mike (G)
Raupach, Dale (S)
Rearick, Todd (G)
Rudy, Kenneth (S)
Sahadewan, Kanaga (G)
Sipos, Rick (S)
Turso, James (G)
Williams, Jim (G)
Voth, Marcus (F)
Yeh, Tsung-Kuang (G)
Xu, Xiangjun (G)

COLLEGE OF SCIENCE

Biology

Thomas, Gene (F)

Chemistry

Allcock, Harry (F)
Ambrosio, Archel (G)
Dudley, Gary (G)
Diefenbach, Ursula (G)
Fitzpatrick, Richard (G)
Grune, Guerry (G)
Pucher, Shawn, (G)
Silverberg, Eric (G)
Smith, Dawn (G)
Turner, M. L. (G)
Visscher, Karyn (G)

Physics

Sokol, Paul (F)
Enders, Todd (G)

INTERCOLLEGIATE PROGRAMS

Health Physics

Boeldt, Eric (S)
Cranlund, Rodger (S)
Hollenbach, Donald (S)

INDUSTRIES

Alliant Tech Systems	Rahn, Brian
Army Pulsed Reactor Facility	Oliver, Mark
Armed Forces Radiobiology Research Institute	Moore, Mark
Bettis Labs	Glickstein, Stan
Carpenter Technology	Balliett, Thomas
CB-Tech	Bleistein, Charles
Clarion University, Biology Department	Vento, Frank
David Sarnoff Research Center	Ipri, Alfred
E Systems, ECI Division	Dobson, Robert
	Herbst, J.
	Uber, Craig
Fairway Laboratories	Markel, William L. Jr.
GEC Marconi	Murtaugh, Steve
	O'Neill, Jerre
Geochemical Testing	Bergstresser, Tim
Harris Semiconductor	Merges, John F.
Honeywell	Collins, Dennis
	Hildebrand, K.
Kearfott	Breen, Larry
	Brinkman, J.
	Walendenski, William
Mine Safety Appliance Company	Hendrickson, J.
National Sanitation Foundation	Miller, Michael P.
Northeast Technology Corporation	Kline, Don
	Lindquist, Kenneth O.
	Vonada, Doug
Polymer Chemistry Innovations	McClain, Michael
P. R. Hoffman Materials Processing Corporation	Casey, Ken
	Kingsborough, Lee
Q. C. Inc.	Stacer, Nancy
Raytheon	Callahan, K.
	Enriquez, G. J.
	Mulford, S.
	Nordberg, M.
	Russell, R.
	Schulz, P.
	Stransky, D. F.
Sandia National Laboratory	Kelly, John
Seewald Laboratories	Chianelli, Robert E
Tru-Tech	Boothe, Mike
	Flanagan, Mike
	Landry, Jeff

UNIVERSITIES

University of Maryland	Rasera, Robert L.	Professor of Physics
Clarion University	Vento, Frank	Professor of Geology

MISCELLANEOUS

Various Cobalt -60 irradiations for high school classes' research projects.

APPENDIX B

APPENDIX B
FORMAL TOUR GROUPS

JULY 1991 JUNE 1992	DAY	NAME OF TOUR GROUP	NUMBER OF PARTICIPANTS
July	1	PA Governor's School	64
	16	Engineering Scholars Academy	25
	17	Soviet Students	35
	18	See the Future	25
	18	Soviet Students	32
	19	Best Kodak Program	26
	22	Conservation Leadership School	13
	25	Good Shepherd Lutheran Church	10
	26	Enter 2000	27
	29	Nuclear Concepts Sponsors	4
August	1	IUP	13
	7	GPU Nuclear	18
	28	PSU College of Engineering	7
	29	Food Service Class	21
September	4	New England Nuclear	4
	17	FERMI Group	7
	26	IPAC	3
October	8	Engineering Students	4
	12	Open House	229
	14	Honor's Students	6
	16	Materials Science 101	43
	16	NDE Showcase	3
	17	Materials Science 101	57
	21	La Vie Yearbook	1
	31	Bi Science III	12
November	4	Jr. Science Symposium HS	14
	6	Utility Group	20
	6	Boy Scouts	37
	8	Williamson HS	27
	11	Union City HS	13
	12	Glendale HS	49
	13	Engr. Applied Science Interest House	8
	14	Glendale HS	46
	14	Northwest HS	47
	15	Materials Science 101	77
	18	Johnsonburg/Kane HS	14
	19	Punxsutawney HS	15
	19	Boy Scout Troop 31	28
	26	Biomechanical Engr. Grad. Student & Family	2
	27	Manahan's Group - Tokyo	14
December	3	Westinghouse	2
	4	Greensburg - Salem HS	20
	16	Carlisle HS	20
January	15	Police Services Retraining	20
	17	Berlin HS	5
	17	Jersey Shore HS	14

APPENDIX B
FORMAL TOUR GROUPS
(Continued)

JULY 1991 JUNE 1992	DAY	NAME OF TOUR GROUP	NUMBER OF PARTICIPANTS
January	20	State College High School	19
	22	Police Services Retraining	19
February	14	Entomology Class	7
	21	Office of Physical Plant	11
	21	Ag Engr. Alumni	12
	21	E. Mech. 440 - Hughes	40
	22	Engineering Week - Open House	384
March	9	Redland HS	19
	17	Boy Scouts	20
	18	Daniel Boone HS	15
	25	Science & Technology	52
	27	Science & Technology	55
	30	Berwick HS	13
April	1	Wyomissing HS	17
	3	Marion Center	9
	6	Fuel Science	47
	6	State College HS-German Exchange Students	19
	7	Physical Science III	18
	8	Northern Bedford	21
	8	Fuel Science	22
	8	Carmichael HS	21
	15	Bellefonte HS	27
	15	Nittany Chemical	23
	20	State College HS	10
	21	Puerto Rico Scholars	5
	24	St. Mary's HS	20
	24	Ridgway HS	17
	27	Cambria Heights	74
May	6	Muncy HS	34
	13	Central HS - Martinsburg PA	24
	15	Nuclear Concepts Followup	12
	16	Graduation Students/Parents	30
	16	US Navy	13
	18	Warren HS	9
	29	Dedication Guests	103
	29	Dedication Tour	18
	29	Press Conference	10
	30	Public Open House	184
June	5	University of Pittsburgh	9
	8	College Professor & Students	5
	8	Westmont Hilltop	8
	19	Altoona Scholars	8
	19	Local Area High Schools	10
	24	GPU Nuclear	20
	24	Physics Teachers	14
	29	Political Science Students	5