PENN STATE BREAZEALE REACTOR

Annual Operating Report, FY 90-91
PSBR Technical Specifications 6.6.1
License R-2, Docket No. 50-5

Reactor Utilization

The Penn State Breazeale Reactor (PSBR) is a TRIGA Mark III facility capable of 1 MW steady state operation, and 2000 MW peak power pulsing operation. Utilization of the reactor and its associated facilities falls into three major categories:

EDUCATION utilization is primarily in the form of laboratory classes conducted for graduate and undergraduate students and numerous high school science groups. These classes vary from neutron activation analysis of an unknown sample to the calibration of a reactor control rod. In addition, an average of 2000 visitors tour the PSBR facility each year.

RESEARCH accounts for a large portion of reactor time which involves Radionuclear Applications, Neutron Radiograpy, 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 continuously offered and are tailored to meet the needs of the participants. Individuals taking part in these programs fall into such categories as power plant operating personnel, graduate students, and foreign trainees.

The PSBR facility operates on an 8 AM - 5 PM shift, five days a week, with an occasional 8 AM - 8 PM or 8 AM - 12 Midnight shift to accommodate reactor operator training programs or research projects.

Summary of Reactor Operating Experience

Technical Specifications requirement 6.6.1.a.

Between July 1, 1990 and June 30, 1991, the PSBR was

critical for	521 hours	or 2.1 hrs/shift
subcritical for	334 hours	or 1.3 hrs/shift
used while shutdown for	459 hours	or 1.9 hrs/shift
Total usuage	1314 hours	or 5.3 hrs/shift

The reactor was pulsed a total of 111 times with the following reactivities:

less than $2.00	33
$2.00 to $2.50	78
greater than $2.50	0

The square wave mode of operation was used 74 times to power levels between 100 and 500 KW.

Total energy produced during this report period was 318 MWH with a consumption of 16 grams of U-235.

Unscheduled Shutdowns

Technical Specifications requirement 6.6.1.b.

The 8 unplanned scrams during the July 1, 1990 to June 30, 1991 period are described below.

July 13, 1990 - A linear power scram occurred during an attempted 200 KW square wave operation. The operator initiated the square wave from a steady state power of 100 watts without first turning the range switch to 300 KW. Thus, the automatic control system engaged prematurely. When the operator belatedly upranged the power switch, the automatic system sensed a large power difference between the demand power and actual power and withdrew reg rod; since there is no period information to the auto system in square wave mode the power increased at a faster than normal rate. The operator initiated a manual scram concurrent with the system linear scram.

July 31, 1990 - A linear power scram occurred when a student in a nuclear engineering reactor operations course turned the range switch the wrong way.

August 23, 1990 - The operator manually scrammed the reactor upon receiving a pneumatic transfer system radiation alarm during a rabbit run. The RM-14 radiation monitor that monitors the radiation in the system's surge volume was set on too sensitive a range (x10 instead of x100). A notice was placed on the monitor to remind operators of the proper setting. The procedure for using the pneumatic transfer system was also modified to reflect the x100 requirement.

October 15, 1990 - An unplanned power failure to the reactor building caused a reactor scram from 1 MW.

January 16, 1991 - A linear power scram occurred when an operator trainee turned the range switch the wrong way while increasing power.

January 31, 1991 - A reactor period scram occurred when the operator turned the period switch to the test position instead of the calibrate position. A previous operator had not returned the test potentiometer to the zero position. The source was being moved during a nuclear engineering reactor operations course to check for criticality as a training excercise; the operator was attempting to momentarily defeat the period scram while a person on the bridge removed the source from the core.

April 15, 1991 - A linear power scram occurred during a square wave attempt. The operator failed to upscale the reactor power range switch before firing the transient rod to attempt the square wave.

May 23, 1991 - An unplanned power failure to the reactor building caused a reactor scram from 1 MW.

Major Maintenance With Safety Significance

Technical Specifications requirement 6.6.1.c.

No major preventative or corrective maintenance operations with safety significance have been performed during this report period.

Major Changes Reportable Under 10 CFR 50.59

Technical Specifications requirement 6.6.1.d.

Facility Changes

September 21, 1990 - The light beam alarm in the reactor beam hole lab was eliminated. The purpose of this alarm was to alert the reactor operator if someone entered the neutron beam area without the operator's permission. A new system was installed featuring a normally locked beam gate to control access to the neutron beam area. Opening this beam gate when any one of the seven beam hole doors is open, gives a local alarm and also an alarm to the reactor operator. In addition, opening an outside access door to the beam hole lab monitored area would also trigger the same alarm to the reactor operator (this door is normally bolted and locked from the inside).

November 19, 1990 - An existing six foot section of six inch pipe in the primary side of the reactor heat exchanger was cut at two locations and a section was removed; flanges were welded on the pipe at the cuts to accommodate a magnetic flow sensor that has its own set of flanges. The flow sensor was installed to provide information for a new heat balance method to determine the reactor's thermal power. A flanged spool piece has been fabricated to replace the flow sensor if it has to be removed for some reason.

March 6, 1991 - A four foot section of bolted flanged six inch pipe was removed from the primary side of the reactor heat exchanger to install a well coupling to accommodate a temperature probe. The pipe section was then returned to the previous location. The temperature probe is used to provide information for a new heat balance method to determine the reactor's thermal power.

March 25, 1991 - Infrared motion detectors were installed to replace ultrasonic motion detectors in the fuel storage room to meet changes in the facility's modified Physical Security Plan.

Procedures

All procedures are reviewed as a minimum biennially, and on an as needed basis. Changes during the year were numerous and no attempt will be made to list them. A current copy of all facility procedures will be mad. ailable on request. Since none of the procedure changes were a result of Tech Specs changes, none of the procedure changes are considered major.

New Tests and Experiments

None having safety significance.

Radioactive Effluents Released

Technical Specifications requirement 6.5.1.e.

Liquid

There were no liquid effluent releases under the reactor license for the report period. Liquid from the regeneration of the reactor demineralizer is evaporated and the distillate recycled for pool water makeup. The evaporator concentrate is dried and the solid salt residue is disposed of in the same manner as other solid radioactive waste at the University.

Liquid radioactive waste from the radioisotope laboratories at the PSBR is under the University byproduct materials license and is transferred to the Health Physics Office for disposal with the waste from other campus laboratories. Liquid waste disposal techniques include storage for decay, release to the sanitary sewer as per 10 CFR 20, and solidification for shipment to licensed disposal sites.

Gaseous

The only gaseous effluent is Ar-41, which is released from disolved air in the reactor pool water, dry irradiation tubes, and air leakage from the pneumatic sample transfer systems.

The amount of Ar-41 released from the reactor pool is very dependent upon the operating power level and the length of time at power. The release per MWH is highest for extended high power runs and lowest for intermittent low power runs. The concentration of Ar-41 in the reactor bay and the bay exhaust was measured by the Health Physics staff during the summer of 1986. Measurements were made for conditions of low and high power runs simulating typical operating cycles. Based on these measurements, an annual release of between 236 mCi and 714 mCi of Ar-41 is calculated for July 1, 1990 to June 30, 1991, resulting in an average concentration at the building exhaust between 15% and 44% of the MPC for unrestricted areas. These values represent the extremes, with the actual release being between the two values. The maximum fenceline dose using only dilution by the 1m/s wind into the lee of the building is on the order of 0.2 % to 0.6 % of the unrestricted area MPC.

During the report period, several irradiation tubes were used at high enough power levels and for long enough runs to produce significant amounts of Ar-41. The calculated annual production was 69 mCi. Since this production occurred in a stagnant volume of air confined by close fitting shield plugs, most of the Ar-41 decayed in place before being released to the reactor bay. The reported releases from dissolved air in the reactor pool are based on measurements made, in part, when a dry irradiation tube was in use at high power levels; the Ar-41 releases from the tubes are part of rather than in addition to the release figures quoted in the previous paragraph.

The use of the pneumatic transfer systems was minimal during this period and any Ar-41 releases would be insignificant since they operate with CO-2 and Nitrogen as fill gases.

Environmental Surveys

Technical Specifications requirement 6.6.1.f.

The only environmental surveys performed were the routine TLD gamma-ray dose measurements at the facility fenceline and at control points in residential areas several miles away. This reporting year's measurements tabulated below represent the July 6, 1990 to June 30, 1991 period. A comparison of the North, West, East, ane South fenceline measurements with the control measurements at Houserville (1 mile away) and Bellefonte (10 miles away) show the differences to be similar to those in the past.

	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	Total
Fence North	21.46	14.69	19.95	16.49	72.59
Fence West	18.96	15.06	19.40	15.85	69.27
Fence East	23.90	14.05	20.93	16.92	75.80
Fence South	18.67	13.83	19.26	16.38	68.14
Control-Bellefonte	22.44	14.35	20.28	16.56	73.63
Control-Houserville	14.48	12.97	15.07	13.15	55.67

Personnel Exposures

Technical Specifications requirement 6.6.1.g.

No reactor personnel or visitors received dose equivalents in excess of 25% of the permissible limits under 10 CFR 20.

PENNSTATE

RADIATION SCIENCE AND ENGINEERING CENTER

COLLEGE OF ENGINEERING

THIRTY-SIXTH ANNUAL PROGRESS REPORT

AUGUST 1991

CONTRACT DE-ACO7-761DO1570
SUBCONTRACT C88-101857

U.Ed. ENG 92-30

THIRTY-SIXTH ANNUAL PROGRESS REPORT

PENN STATE RADIATION SCIENCE AND ENGINEERING CENTER

July 1, 1990 to June 30, 1991

Submitted to:

United States Department of Energy

and

The Pennsylvania State University

By:

Marcus H. Voth (Director)
Terry L. Flinchbaugh (Editor)
Penn State Radiation Science and Engineering Center
Department of Nuclear Engineering
The Pennsylvania State University
University Park, PA 16802

August 1991

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PREFACE

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-sixth Annual Progress Report (July 1990 through June 1991) 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

The Radiation Science and Engineering Center (RSEC) sustained its record of providing educational and research support for a broad spectrum of users. In addition, major new achievements included the following:

* Fabrication of the new digital computer based reactor control system was completed, the system was delivered and site-tested and a license amendment request was filed with the Nuclear Regulatory Commission. Advanced control theory research commenced using the new control system.

* The RSEC staff was awarded a three year National Science Foundation grant of $212,063, for a program for high school science teachers entitled, "Nuclear Concepts and Technological Issues Institute and Educational Outreach Program." Matching funds were provided by industry sponsors.

* The RSEC staff was awarded a $39,123 Department of Energy grant for reactor radiation monitoring instrumentation and new gamma spectroscopy equipment.

* Instructional laboratory equipment was upgraded through the addition of computer equipment and new ionization chambers. Funding was provided by student surcharge money ($4,228) and the Ben Franklin Partnership Program ($4[illegible],000).

* The Perturbed-Angular Correlation (PAC) Laboratory at the RSEC was expanded by the addition of a second complete PAC spectrometer, new computer equipment and a Mössbauer spectrometer.

* The RSEC "Quality Assurance Program for Analysis, Examination and Testing of Components or Systems," was effectively implemented for the first time.

* The RSEC staff hosted the annual meeting of the Test, Research and Training Reactor management and an NRC seminar for Non-Power Reactors

* A brochure was prepared with specification sheets for the various RSEC facilities and equipment.

* One RSEC staff member received a Reactor Operator license from the Nuclear Regulatory Commission.

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.

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II. PERSONNEL

The position of Deputy Director was eliminated when Ira McMaster retired at the end of the previous fiscal year. His duties were assumed by Terry Flinchbaugh in his expanded role as Manager of Operations and Training and Dan Hughes in his new position as Manager of Engineering Services

Joseph Bonner resigned his position as Research Assistant on August 15, 1990. Robert Gould was hired as a project assistant on September 4, 1990. Patrick Boyle was hired as a reactor supervisor/nuclear education specialist on November 1, 1990.

Rebecca Batschelet resigned her position as environmental analyst in the Low Level Radiation Monitoring Lab (LLRML) on August 10, 1990. Hermina Boyle, who had worked in the lab in a wage payroll position for 7 weeks, assumed the environmental analyst position effective September 4, 1990.

Bonnie Ford resigned her position as supervisor of the LLRML on September 23, 1990. Michael McClain assumed the supervisor position on October 1, 1990 and resigned on March 19, 1991.

Hermina Boyle moved from the analyst to supervisor position in the LLRML on March 19, 1991. Julie Goodfellow, who had worked in the LLRML for five weeks in a wage payroll position, assumed the analyst position on April 15, 1991.

Thiery Daubenspeck, who had worked at the LLRML on a part time basis during the Spring 1991 semester, began work in a full time wage payroll position on May 13. Other LLRML wage payroll and work-study help during the year was provided by Calvin Sleppy, Ed Rentanen, Ha Cheung and Brett Kellerman.

Jennifer Wellar resigned as secretary and receptionist on November 24, 1990. Lisa Large worked as a wage payroll secretary from December 3, 1990 to January 2, 1991 when she assumed the secretary and receptionist position. Kim Conlin was hired on April 3, 1991 as a wage payroll secretary.

Reactor work-study and wage payroll positions were filled by Richard Brown, Thiery Daubenspeck, John DeMarco, Steve Maderas, Steve Nornhold, Jeff Nugent and Ken Sahadewan.

On January 1, 1991, the following changes occurred in the membership of the Penn State Reactor Safeguards Committee. Jerry Blakeslee (Assistant Superintendent of Plant, Pennsylvania Power and Light) resigned from the committee after seven years of service, the last four as chairman. Fan-bill Cheung (Associate Professor of Mechanical Engineering) and Masoud Feiz (Assistant Professor of General Engineering) both resigned from the committee after each serving a three year term. Joining the committee for their first three year terms are Pat Loftus (Manager, Product Licensing at Westinghouse), Ed Figard (Supervisor of Maintenance at Pennsylvania Power and Light) and Dan Hughes (Research Assistant). Ward Diethorn (Professor of Nuclear Engineering) who had joined the committee in 1989 to fill out a vacant unexpired term, accepted an appointment for a three year term. Committee member Gordon Robinson (Associate Professor of Nuclear Engineering) assumed the chairmanship on January 1, 1991.

On January 1, 1991, Frank Ruddy (Senior Scientist, Westinghouse) replaced John Bartko (Advisory Scientist - retired, Westinghouse) on the Penn State Users Advisory Committee.

TABLE I

Personnel

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

* Licensed Operator
**Licensed Senior Operator

Clerical Staff

K. M. Conlin	Secretary - wage payroll
S. K. Ripka	Facility Secretary
L. D. Large	Secretary and Receptionist
J. L. Wellar (resigned)	Secretary and Receptionist

Technical Service Staff

J. E. Armstrong	Maintenance Worker
R. L. Eaken	Experimental and Maintenance Mechanic

Student Work-Study or Wage Payroll

R. Brown	S. Nornhold
H. Cheung	J. Nugent
T. Daubenspeck	E. Rentanen
J. DeMarco	K. Sahadewan
B. Kellerman	C. Sleppy
S. Madaras	

Penn State Reactor Safeguards Committee

*J. A. Blakeslee	Chairman, Assistant Superintendent of Plant, Pennsylvania Power and Light Susquehanna Steam Electric Station
*F. B. Cheung	Associate Professor, Mechanical Engineering, Penn State
W. S. Diethorn	Professor, Nuclear Engineering, Penn State
E. W. Figard	Supervisor of Maintenance, Pennsylvania Power and Light Susquehanna Steam Electric Station
*M. Feiz	Assistant Professor, General Engineering, Penn State
R. W. Granlund	Health Physicist, Intercollege Research Programs and Facilities, Penn State
D. E. Hughes	Research Assistant, Penn State Radiation Science and Engineering Center
P. Loftus	Manager, Product Licensing, Westinghouse
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 1991

Penn State Users Advisory Committee

*J. Bartko	Advisory Scientist, Westinghouse
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

*served through January 1, 1991

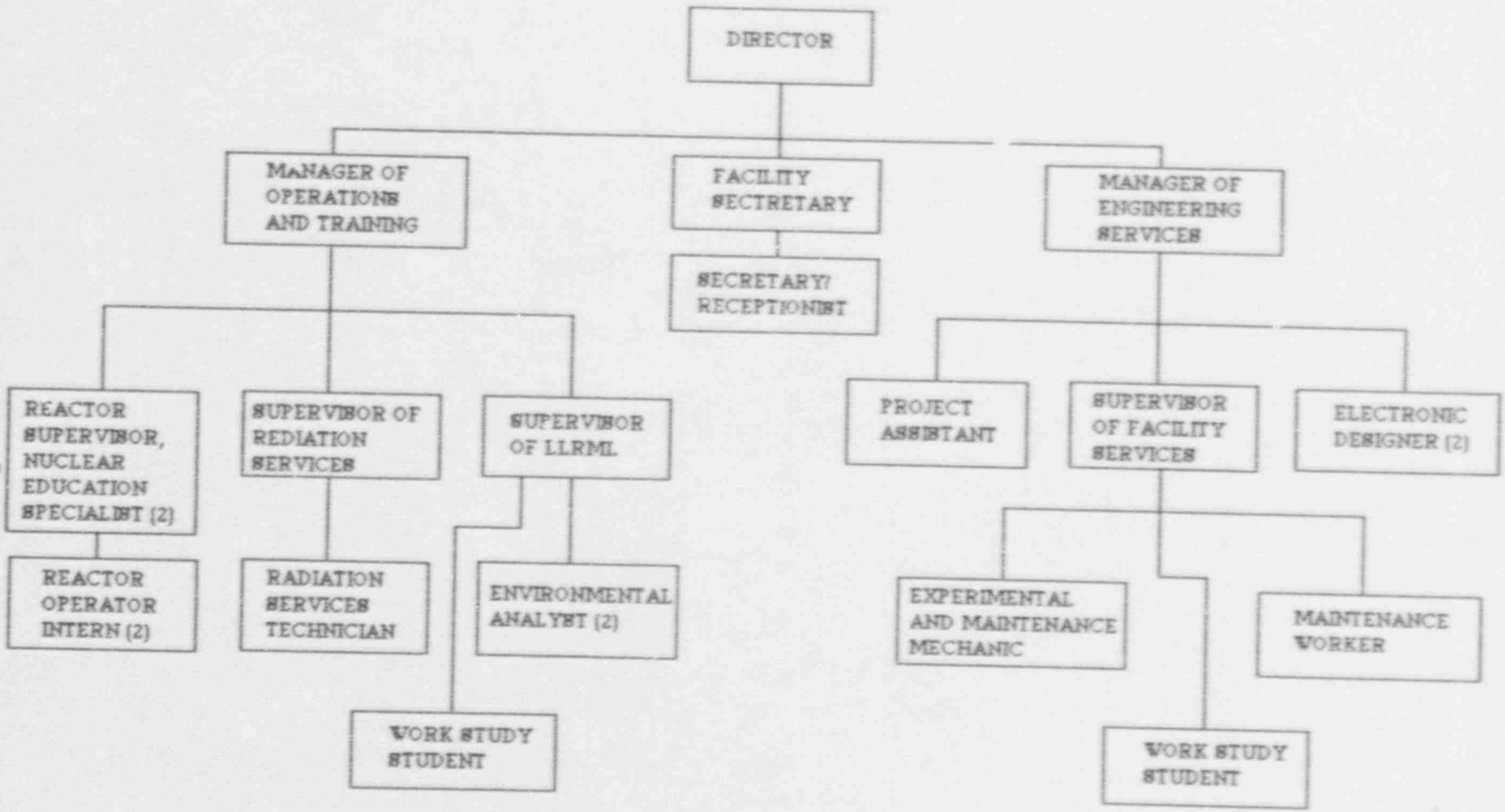

FIGURE 1 RSEC Organization Chart

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. One of the Unplanned Scrams Resulting from Personnel Action was by a student in the NucE 444 course, Nuclear Reactor Operations Laboratory, one was by a staff operator trainee and three were by licensed staff operators. It should be pointed out that a scram shuts down the reactor before a safety limit is reached. The unplanned scrams resulting from Abnormal System Operation were due to electrical failure and system operational problems.

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 1990, Penn State faculty member Samuel H. Levine (Nuclear Engineering) conducted an audit of the PSBR to fulfill a requirement of the Penn State Reactor Safeguards Committee charter. The reactor staff has implemented changes suggested by that report, all of which exceed NRC requirements.

During January of 1991, a NRC routine inspection was conducted of activities authorized by the materials license 37-00185-05 for the Cobalt-60 facility. A violation (senior operator on occasion inserted and removed samples for vertical tube irradiation without wearing a finger-ring dosimeter) was cited. Corrective action has been taken by the reactor staff to prevent recurrence. No other violations were observed.

During February of 1991, a NRC routine inspection was conducted of activities authorized by the R-2 reactor license and the SNM-95 special nuclear materials license. A licensee-identified violation of a technical specification of License R-2 (licensed operator briefly stepping outside of the control room with the reactor not secured) was reviewed. No other violations were observed. The reactor staff has implemented changes suggested by the audit which exceed NRC requirements.

TABLE 2

Reactor Operation Data
July 1, 1988 - June 30, 1991

		88-89	89-90	90-91
A.	Hours of Reactor Operation			
	1. Critical	566	507	521
	2. Subcritical	416	305	334
	3. Fuel Movement	28	0	5
B.	Number of Pulses	222	97	111
C.	Number of Square Waves	108	70	74
D.	Energy Release (MWH)	233	331	318
E.	Grams U-235 Consumed	12	17	16
F.	Scrams			
	1. Planned as Part of Experiments	42	23	36
	2. Unplanned - Resulting From			
	a) Personnel Action	6	4	5
	b) Abnormal System Operation	3	3	3

TABLE 3

Reactor Utilization Data
Shift Averages
July 1, 1988 - June 30, 1991

	88-89	89-90	90-91
A. Reactor Usage			
1. Hours Critical	2.2	2.1	2.1
2. Hours Subcritical	1.7	1.3	1.3
3. Hours Shutdown	2.4	1.6	1.9
4. Reactor Not Available	0.1	0.0	0.0
TOTAL HOURS PER SHIFT	6.4	5.0	5.3
B. Type of Usage - Hours			
1. Industrial Research and Service	0.9	1.1	0.8
2. University Research and Service	2.2	1.8	2.1
3. Instruction and Training	1.7	0.9	1.2
4. Industrial Training Programs	0.1	0.1	0.1
5. Calibration and Maintenance	1.5	1.2	1.1
C. Users/Experiments			
1. Number of Users	3.3	2.4	2.4
2. Pneumatic Transfer Samples	1.2	1.3	0.5
3. Total Number of Samples	4.3	3.6	2.5
4. Sample Hours	2	2.6	2.2
D. Number of 8 Hour Shifts	251	240	247

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, 1991 approximate total of 5,600 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 205 KR/Hr in a 3" ID tube and 119 KR/Hr in a 6" ID tube are available as of July 1, 1991.

Efforts continue to obtain 17,000 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, 1988 - June 30, 1991

		88-89	89-90	90-91
A.	Time Involved (Hours)			
	1. Set-Up Time	336	358	215
	2. Total Sample Hours	6,795	11,692	14,277
B.	Numbers Involved			
	1. Samples Run	1,343	1,433	756
	2. Different Experimenters	42	23	30
	3. Configurations Used	3	3	3
C.	Per Day Averages			
	1. Experimenters	1.31	1.95	0.8
	2. Samples	5.39	5.76	3.04

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, utility training programs, formal laboratory courses and many continuing education programs and tours.

Staff member Patrick Boyle prepared for an NRC operator examination during the year. He passed his NRC exam in April and received his operator's license in May.

In-house reactor operator requalification consisted of an oral examination on abnormal and emergency procedures given by D. C. Raupach and an operating test given by C. C. Davison.

A three-day Reactor Start-Up Experience Program was offered for Boston Edison Company for ten people in January 1991. The Senior Reactor Operators on the RSEC staff, M. E. Bryan, C. C. Davison, D. E. Hughes, T. L. Flinchbaugh, E. Hannold and D. C. Raupach, provided the console instruction in the program and the coordination of the program was done by T. L. Flinchbaugh. M. H. Voth provided two lectures for the program.

The fifth session of the Pennsylvania Governor's School for Agricultural Sciences was held at Penn State's University Park campus during the summer of 1990. Sixty-four high school scholars participated in the five week program which began on July 1, 1990. 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 course was conducted at Penn State's RSEC by Candace Davison and Ken Sahadewan of the RSEC staff, and Mike Zarger, a NUCE graduate student, who is also a Pennsylvania certified physics teacher. 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 9 - August 3, 1990 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. Eighteen secondary science teachers from six different states (Pennsylvania, Maryland, Ohio, New York, Massachusetts and Alaska), and Korea participated in the program.

Support for the program included funding of nearly $10,000 from the U.S. Department of Energy, Office of Industry and Science Education, with the remainder of program costs covered by private industry sponsorship. Full sponsorship of participants was provided by Baltimore Gas and Electric Company, Cleveland Illuminating Company (Perrry Nuclear Power Plant), Duquesne Light Company, Edison Electric Institute, Korea Atomic Industrial Forum, Limerick Community Education Program (through the Philadelphia Electric Company), New York State Electric and Gas Company, Penelec, Rochester Gas and Electric Corporation and Westinghouse Electric Corporation. The American Nuclear Society, Bellefonte School District, Boston Edison Company and GPU Nuclear Corporation provided partial support for teachers. Materials were obtained from the U.S. Department of Energy, USCEA, ANS and other sources. General Electric Company donated a full size Chart of the Nuclides to each participant.

The institute was coordinated by Candace Davison and was conducted through Penn State's Continuing Education Office. Joseph Bonner, Research Assistant, provided the main instruction. 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 Mrs. Ginger King from the U.S. Department of Energy, Office of Civilian Radioactive Waste Disposal and Management, Ms. Lori Howard from the West Valley Demonstration Project, Mr. John Schreiber retired from the U.S. D.O.E. and formerly with the Shippingport Decommissioning Project and Mr. Jack Devine from GPU Nuclear Corporation.

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 with assistance from Guy Anderson, a chemistry teacher from the Bald Eagle Area School District. 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, Hershey Medical Center and Three Mile Island 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.

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 Bucknell, Juniata and Wilkes College. Bucknell University and Clarion University used the RSEC for research projects.

A total of 424 students and teachers from 19 high schools and 3 colleges came to the RSEC for experiments and instruction (see Table 5). Candace Davison and Steve Wukitch 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 part of a larger program on campus through Penn State Continuing Education Programs. The student programs included: the Kodak BEST (Business, Science, Engineering and Technology) program, the Secondary Saturday Science Academy, the SEE the Future program and the Upward Bound program for minority and "at risk" students. Thirty-seven teachers from the Harrisburg area participated in a full day of experiments as part of the course "Exploring the Nuclear Option". Thirty-four teachers from the Enter-2000 program and twenty-six teachers and guidance counselors from the RENEW program (through ECSEL) 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 77 tours for 2,055 persons.

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

Semester	Course	Instructor	Students	Hours
Summer 1990	SciEd 497 - Exploring the Nuclear Option	C. C. Davison	20	4
Summer 1990	NucE 497B-Nuclear Concepts	C. C. Davison	18	4
Summer 1990	NucE 444-Nuclear Reactor Operations	J. J. Bonner	9	22
Summer 1990	Food Science 313-Process Plant Product	R. B. Beelman	27	2
Fall 1990	NucE 401-Introduction to Nuclear Engineering	S. H. Levine	25	3
Fall 1990	NucE 451-Reactor Physics	E. S. Kenney W. A. Jester	18	37
Fall 1990	Physics 457-Experimental Physics	P. E. Sokol	2	7
Spring 1991	NucE 450-Radiation Detection and Measurement	G. L. Catchen W. A. Jester	14	12
Spring 1991	NucE 444-Nuclear Reactor Operations	D. E. Hughes	8	24
Spring 1991	NucE 505-Reactor Instrumentation and Control	E. S. Kenney	6	3
Spring 1991	Entomology 456-Insect Pest Management	A. Hower	5	2
Spring 1991	EMch 440-Nondestructive Evaluation of Flows	C. E. Bakis	25	1
Spring 1991	NucE 445-Nuclear Digital Instrumentation	E. S. Kenney	16	90
Spring 1991	Physics 599-Special Topics	P. E. Sokol	6	15
Summer 1991	SciEd 497-Exploring the Nuclear Option	C. C. Davison	17	4

Zenon Lopaciuk, a prior International Atomic Energy Agency (IAEA) Fellow in the Nuclear Engineering Department, returned from his native Poland in February 1991 under IAEA sponsorship to assist in the installation of a new control system for the Penn State TRIGA reactor. The AECL Technologies/Gamma Metrics system features a state-of-the-art digital control, protection and monitoring system with an integral analog system for safety functions. Mr. Lopaciuk attended training classes for Penn State licensed reactor operators and assisted in pre-installation operational checkout of the system, gaining familiarity with the hardware and software design. He participated in experiments to evaluate the system control performance and conducted experiments with Penn State faculty in automatic control theory.

In December of 1990 and January of 1991, a total of 38 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.

Assisting the reactor operating staff and continuing education staff in carrying our the above mentioned educational programs were several other staff members. S. K. Ripka, J. L. Wellar, L. Large and K. Conlin provided secretarial services, D. S. Vonada and M. E. Bryan provided electronic design and maintenance services and K. E. Rudy, R. L. Eaken and J. E. Armstrong provided mechanical maintenance services.

During the past year, the RSEC operating staff has maintained reactor operator competence and safe facility operation through training and requalification, and shared the many man-years of operating experience with operator trainees from utilities. 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
1990-1991 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 but one group conducted the Approach to Critical Experiment 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
October	1	Greensburg High School Cheryl Harper, Eric Eisaman	11
	17	Antietam High School Helen Luckenbach	42
November	13	Punxsutawney High School William Stuchell	13
	13	Daniel Boone High School Larry Tobias, J. Lenhart	15
January	18	Jersey Shore High School James Allen	20
	25	Bucknell University J. Ben Austin	5
February	1	State College High School Carolyn Holt, David Dillon	14
	25	State College High School Mrs. Hershey	33
	27	State College High School Dave Klindienst	17
March	1	State College Todd McPherson	32
	12	Redland High School Robert Lighty, Elaine Foster	20
	13	Bellefonte High School Craig Munnell, Walt Young	19
	21	Twin Valley High School Douglas Mountz	28
	27	N. Bedford High School Michelle Claar	8
April	3	Marion Center High School John Petrosky	7
	9	Wilkes College	2
	11-12	Suffern High School Howard Tokosh, Robert Neff	10

TABLE 5

University Reactor Sharing Program
College and High School Groups
1990-1991 Academic Year
(Continued)

Month		School and Teacher	Number of Students & Teachers
	15	Cowanesque High School Ed Stuart, Georgia McCutcheon	31
	18	Carmichaels High School Pat Gibson	12
	23	Loyalsock High School John German	14
	25	Juniata College Norm Siems	5
	26	St. Mary's High School William Scilingo	24
	26	Ridgway High School Ernest Koos	12
May	3	Chartiers-Houston High School Helen Wicker	12
	8	Warren Area High School Dan Giffin	18

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_20 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.

Unfortunately, there has not been any funded research conducted in the last year utilizing the beam lab. However, we have had some funded service work utilizing the beam to measure neutron attenuation of boroflex materials that have seen service in fuel storage pools. We continue to have interest from people looking for solutions to their problems but no large projects have resulted.

During the Fall and Spring 1991 semester, Dr. Sokol of the Physics Department conducted a graduate laboratory project utilizing the neutron beam. The experiment used a chopper to measure the neutron energy spectrum of the beam. Dr. Sokol plans to further develop this experiment and others for future laboratory instruction.

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.

Analyses of samples were performed for Penn State students and faculty members who had samples which needed to be analyzed and did not have time to learn to do their own analyses. In addition to these, laboratory personnel have worked closely with Dr. Ralph Mumma of the Penn State University and Dr. Donald Lisk of Cornell University in conducting research on the trace elements in fly ash. This project has been completed.

A new cooperative research project has been initiated which will involve the neutron activation analysis of samples to be received from the Western Pennsylvania Hospital, Pittsburgh, Pennsylvania. Dr. Quentin Hartwig of Clarion University of Pennsylvania will be assisting with this project.

A project which involved the neutron activation analysis of samples supplied by Stephen G. Warfel, Curator, Archaeology, of The State Museum of Pennsylvania has been comp[illegible]. The samples irradiated were from pottery pieces found at a site near Lancaster, Pennsylvania.

Approximately 161 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 all the regularly used irradiation facilities.

The xenon gas filled gamma detector system has been used on a regular basis for determining the gamma dose received by semiconductors while being irradiated. The GeLi detector multichannel analyzer system which was installed near the reactor poolside continues to be utilized in assisting with release of irradiated samples from the pool.

During the past year another end window gas flow proportional counter system was set up and calibrated for the counting of sulfur pellets. Sulfur pellets are used to determine the fast neutron dosimetry for semi-conductor irradiations. The system was calibrated using a Phosphorus - 32 standard which had been purchased from the National Institute of Science and Technology.

LOW LEVEL RADIATION MONITORING LABORATORY

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.

A spiked sample program was established in 1985 for Pennsylvania Power and Light Company (PP&L). This program is used to ensure analytical quality control of both the sending and receiving laboratories. Using various types of sample media, the LLRML prepares samples of known isotopic concentration, analyzes them, and then splits them in half, shipping them to PP&L's REMP QC Laboratory in Allentown and Controls for Environmental Pollution Inc. in Santa Fe, New Mexico. Thermoluminescent dosimeters are also processed quarterly for PP&L.

THE ANGULAR CORRELATIONS LABORATORY

IX. THE ANGULAR CORRELATIONS LABORATORY

The Angular Correlations Laboratory has been in operation for approximately 5 years. The laboratory, which is located in Room 116 and Room 4 of the RSEC, is under the direction of Professor Gary L. Catchen. The laboratory contains two spectrometers for making Perturbed Angular Correlation (PAC) measurements. One apparatus, which has been in operation for five years, measures eight coincidences concurrently using cesium fluoride detectors. A second spectrometer was acquired this 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. Recently, the National Science Foundation has funded this project and work is underway.

NUCLEAR MATERIALS ENGINEERING LABORATORY

X. NUCLEAR MATERIALS ENGINEERING LABORATORY

During the past year, the hot cell renovation was completed. The upgrades and changes made to the cells include: painting the cell interior with radionuclide diffusion barrier paint, manipulator servicing, creation of a cell-to-cell transfer port for moving specimens between cells, and fabrication of an in-cell shielded container for storage of high activity specimens. The new Instron 8500 mechanical test load frame has been installed inside the mechanical property test cell.

In addition to the changes associated with the hot cells, several new pieces of materials research equipment have been added to the NMEL. An optional measuring microscope with resolution of 0.00005 in. was purchased. The microscope will be used in the near term to measure creep in low melting eutectic alloy melt wires from nuclear pressure vessel surveillance capsules. An annealing furnace was purchased for creep experimentation and for use in sensitizing stainless steel for corrosion research. An electric potential system was also purchased for measuring crack extension in borated stainless steel fracture toughness specimens. The positron annihilation equipment has been set up and calibrated. Positron annihilation spectroscopy is being used to study radiation damage in pressure vessel steels. Discussion of the various research projects conducted in the Nuclear Materials Engineering Laboratory can be found in Chapter XI.

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 reports 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 2 talks, 8 papers, 7 publications, 5 masters' theses, 12 doctoral theses, one bachelor's thesis and one senior honor's thesis. 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, 56 faculty and staff members, 39 graduate students and 12 undergraduate students have used the facility for research. This represents a usage by 19 departments or sections in 5 colleges of the University. In addition, 51 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

Agronomy Department

BIORESTORATION OF PYRIDINE COMPOUNDS POLLUTED SUBSURFACE SEDIMENT

Participants: J. M. Bollag
Zeev Ronen

Services Provided: Gamma Irradiation

The success of soil inoculation with pollutant-degrading bacteria is very often limited by competition with soil native microflora. The pollutant degrading organism very often fails to degrade the target compound because of this competition.

In order to test the extent of competition between the introduced bacteria and native microflora, soil samples were sterilized by gamma irradiation (5 MegaRads).

The activity of the introduced bacteria in the sterile soil was higher than in non-sterile soil. Thus, competition is very likely a factor that controls the success of inoculation for enhanced degradation.

Doctoral Thesis:

"Biorestoration of Pyridine Compounds Polluted Subsurface Sediment," Ronen, Zeev, Department of Agronomy, J. M. Bollag, advisor. (In progress)

Chemistry Department

GAS PERMEABILITY OF POLY(ARYLOXYPHOSPHAZENES)

Participants: H. R. Allcock
W. D. Coggio
C. J. Nelson

Services Provided: Gamma Irradiation

The gas permeabilities of poly(aryloxyphosphazenes) with the general structure $[NP(R)_x(OC_6H_5)_{2-x}]_n$ where $x \le 2$ and R = $OC_6H_4SiMe_3$, $OC_6H_4SiMe_2Ph$, $OC_6H_4SiMePh_2$, OC_6H_4Br and OCH_2CF_3 were investigated. In addition, metal containing polymers with structures $[N_3P_3(OCH_2CF_3)_4(\_-C_5H_4)_2Fe]_n$ and $[N_3P_3(OCH_2CF_3)_{1.9}(FeCp(CO)_2)_{0.1}]_n$ were synthesized and gas permeation studies carried out.

The permeability of films of these polymers to O_2, N_2, CO_2, He and CH_4 was studied and selectivity ratios established. The effects of crosslinking on both the permeation and selectivity values for films of the silyl derivatized polymers were also investigated. The change in permeability and selectivity as a function of side group, gas pressure, molecular weight and glass transition temperatures (T_g) is discussed.

Chemistry Department

LAMINATION OF ORGANIC POLYMER SURFACES WITH POLY (ORGANOPHOSPHAZENES)

Participants: H. R. Allock
R. J. Fitzpatrick
K. B. Visscher

Services Provided: Gamma Irradiation

The field of biomaterials is one of the fastest growing branches of science today. In order to be an acceptable biomaterial, a complex must be: compatible with tissue surfaces, non toxic and non carcinogenic, chemically inert and stable and must possess an adequate mechanical strength. Some common biomaterials include polymers-such as Teflon and Nylon, metals-such as Titanium alloys and ceramics-such as Aluminum oxides and silicates. Each type of biomaterial has its advantages and disadvantages-such as degradation and low biocompatibility.

Poly(organophosphazenes), however, break down to non-toxic compounds such as phosphates and ammonia upon decomposition and have, in the past, found many applications as biomaterials.

It is the goal of this project to develop a method of laminating common, established, biomaterials (organic polymers) with biocompatible poly(organophosphazenes) and to covalently link the materials at their surface interfaces by ^{60}Co gamma radiation induced crosslinking. In this way, the well established biomedical properties of organic polymers are combined with the non-toxic, hydrophilic properties of poly(organophosphazenes).

Poly(organophosphazenes) may be prepared by the thermal ring opening expansion of hexachlorocyclotriphosphazene. Following polymerization, the chlorine atoms may be replaced via nucleophilic substitution with alkoxy, aryloxy or amino substituents.

These laminated materials will be characterized using solid state NMR and Transmission Electron Microscopy (TEM) and contact angle measurements to show the phosphazene polymer coating the organic polymer after irradiation.

These materials will be tested for biocompatibility, blood compatibility and gas permeability.

Chemistry Department

INTERPENETRATING POLYMER NETWORKS OF POLY (ORGANOPHOSPHAZENES) AND ORGANIC POLYMERS

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

Services Provided: Gamma Irradiation

The purpose of this research is to prepare Interpenetrating Polymer Networks (IPN) of poly(organophosphazenes) and organic polymers. These materials may be used as biomaterials which combine a hydrophobic organic polymer dispersed in a crosslinked hydrophilic phosphazene polymer matrix.

By definition, an IPN is, "a combination of two polymers in network form, at least one of which is synthesized and/or crosslinked in the immediate presence of the other. An IPN can be distinguished from simple polymer blends, blocks and grafts in two ways: (1) An IPN swells, but does not dissolve in solvents, and (2) creep and flow are suppressed." Therefore, it is necessary to use poly(organophosphazenes) that can be easily crosslinked and swelled in aqueous environments for the first polymer matrix. One such material is $[NP(OCH_2CH_2OCH_2CH_2OCH_3)_2]_n$. This hydrophilic poly(organophosphazene) has been shown to crosslink readily under ^{60}Co gamma radiation and this radical crosslinking allows for swelling in organic solvents as well as aqueous media.

Poly(organophosphazenes) are prepared from the thermal ring opening polymerization of hexachlorocylotriphosphazene. Once polymerized, the reactive chlorines may be replaced with alkoxides, aryloxides, primary or secondary amines to obtain stable polymers with properties dependent on the side group.

IPN's are prepared by first crosslinking $[NP(OCH_2CH_2OCH_2CH_2OCH_3)_2]_n$ by exposing it to 3 MegaRads ^{60}Co gamma radiation. The crosslinked polymer is then swollen in a organic monomer such as methyl methacrylate, styrene or acrylonitrile. The swollen, crosslinked polymer/monomer matrix is then sealed, under vacuum, and irradiated for 2 MegaRads ^{60}Co gamma radiation.

IPN's may be characterized in the same manner as polymer blends. Differential Scanning Calorimetry (DSC) determines the thermal transitions of the individual components. IR and solution NMR spectroscopy trace characteristic functional groups in these polymers and Transmission Electron Microscopy (TEM) enables one to see individual polymer domains within the material.

Thus far, samples of crosslinked $[NP(OCH_2CH_2OCH_2CH_2OCH_3)_2]_n$ have been swelled in methyl methacrylate, styrene, acrylonitrile and divinyl benzene. These samples have been irradiated for 2 MegaRads and will be characterized using the aforementioned methods.

The materials prepared in these investigations should exhibit a combination of the properties of the starting materials-a hydrophobic portion dispersed in a hydrophilic matrix. The ideal biomaterial would be composed of each of these types of components-the hydrophilic portion would allow partial solubility in aqueous media while the hydrophobic portions would prevent complete dissolution in aqueous media. Once prepared, these complexes could be used as materials for heart valves, sutures, artificial veins, membranes, drug delivery systems and many other uses.

<u>Chemistry Department</u>

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

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

Services Provided: Gamma Irradiation

Five different poly(alkyl ether)phosphazenes were synthesized in order to study their water solubility behavior as well as their corresponding hydrogels. They are:

Poly[di(methoxyethoxy)phosphazene], poly[di(aminoethoxyethoxy)phosphazene], poly[di(methoxyethoxyethoxy)phosphazene], poly[di(ethoxyethoxyethoxy) phosphazene] and poly[di(butoxy ethoxyethoxy)phosphazene]. It was observed that as the temperature of the aqueous solutions of these polymers increased each of the macromolecules precipitated from solution at a specific temperature. This effect was independent of both the polymer concentration in solution and the pH of the aqueous media. However, poly[di(aminoethoxyethoxy)phosphazene] was fully soluble at all polymer concentration Hydrogels of these polymers were prepared by subjecting them to gamma radiation (1 MegaRads, 5 MegaRads and 10 MegaRads). The crosslinked polyphosphazenes behaved in a similar fashion to their soluble counterparts. As the temperature of the aqueous media increased, the hydrogel became opaque and lost mass (losing imbibed water weight). The weight loss percentage was independent of both the pH of the aqueous media and the radiation dose received. There was no significant decomposition of the polymers nor was there any loss of integrity of the hydrogels through several heating and cooling cycles. Also, this solubility phenomenon was inherent to water and was not observed in other common organic solvents. An explanation of the low critical solubility temperature of the poly(alkyl ether)phosphazenes is provided as well as potential applications of the hydrogels.

Chemistry Department

POLYMER BLENDS OF POLY(ORGANOPHOSPHAZENES) WITH POLY(ORGANOPHOSPHAZENES) AND ALSO WITH ORGANIC POLYMERS

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

Services Provided: Gamma Irradiation

The purpose of this research is to prepare polymer blends composed of poly (organophosphazenes)/poly(organophosphazenes) and poly (organophosphazenes)/ organic polymers. These alloys will be tested as biomaterials.

Polymer blends may occur in a single phase (miscible blends) or multi-phase (immiscible blends) system. Both types of materials have great industrial application and their degree of miscibility may be determined by FT-IR, which determines intermolecular interactions; Scanning Electron Microscopy (SEM), which allows one to look at the individual domains within the system; and Differential Scaning Calorimetry (DSC), which shows the thermal transitions of the material.

The ideal polymer blend biomaterial would be composed of both a hydrophobic and a hydrophilic component-the hydrophilic portion allows partial solubility in aqueous media, and the hydrophobic portion prevents complete dissolution in aqueous media.

We have investigated the blending properties of the following poly(organophosphazenes):

$[NP(HNCH_3)_2]_n$	
$[NP(OCH_2CH_2OCH_2CH_2OCH_3)_2]_n$	Hydrophilic
$[NP(OCH_2OCF_3)_2]_n$	Hydrophobic
$[NP(OC_6H_5)_2]_n$	
$[NP(OC_6H_5\text{-}CO_2CH_2CH_2CH_3)_2]_n$	

The following organic polymers were blended with poly (organophosphazenes):

Poly(vinyl alcohol) Poly(ethylene oxide) Poly(acrylic acid)	Hydrophilic
Poly(vinyl chloride) Poly(styrene) Poly(methyl methacrylate) Poly(4-vinyl pyridine)	Hydrophobic

These polymers represent a cross-section of hydrophobic and hydrophilic poly(organophosphazenes) and organic polymers. The intermolecular interactions between components (hydrogen bonding etc.) helps to induce miscibility in the material.

Blends of every combination of the aforementioned polymers were prepared in many different concentrations. Thus far, DSC data shows $[NP(HNCH_3)_2]_n$ to blend miscible with $[NP(OCH_2CH_2OCH_2CH_2OCH_3)_2]_n$, poly(vinyl chloride), poly(styrene), poly(methyl methacrylate), poly(4-vinyl pyridine) and poly(ethylene oxide)-all due to favorable hydrogen bonded interactions between the components.

Along the same lines, $[NP(OCH_2CH_2OCH_2CH_2OCH_3)_2]_n$ forms miscible blends with poly(vinyl alchol.ol) and poly(acrylic acid).

These materials may be crosslinked with ^{60}Co gamma irradiation to increase their strength and durability. Ultimately, these polymer alloys will be tested for biocompatability and gas permeability.

Doctoral Theses: (Resulting from previous five research projects)

"Combinations of Poly(organophosphazenes) and Organic Polymers." Visscher, K. B., Chemistry, H. R. Allcock, advisor. (In progress)

"Synthesis and Investigation of Novel Cyclic and Polymeric Phosphazenes," Dember, A. A., 1991, Chemistry, H. R. Allcock, advisor.

"Polyphosphazenes: Synthesis and Property Modification," Nelson, C. J., Chemistry, H. R. Allcock, advisor. (In progress)

"Synthesis and Investigation of Poly(organophosphazenes) To Be Used as Biomaterials," Pucher, S. R., Chemistry, H. R. Allcock, advisor. (In progress)

Chemistry Department

^{7}LI QUADRUPOLAR SPECTRUM OF LI ACETATE $2H_2O$

Participants: L. M. Jackman
D. Cizmeciyan
A. J. Benesi

Services Provided: Gamma Irradiation

We are interested in measuring the quadrupole coupling constant of lithium acetate dihydrate using solid state ^{7}Li NMR spectroscopy. We know that the Quadrupole Coupling Constant (QCC) is actually 154.6 kHz from a single crystal. A study was done by BHAT et. al., at the Indian Institute of Science,[1] and using the same compound we keep getting a QCC of ~ 80 kHz. It is thought that this difference could arise because of the t_1 relaxation time of the ^{7}Li nucleus (which is very long: hours). It was suggested in the paper to irradiate the sample for 48 hours with a 2000 Ci γ-ray source to decrease the t_1 of ^{7}Li.

At first sight our QCC is still around 80 kHz, but more investigation needs to be done to be able to explain the results.

[1]S. V. Bhat, A. C. Padmanabhan, R. Srinivasan; Acta Cryst. (1974).B30, 846.

Food Science Department

IRRADIATION OF TURKEY SKIN TO KILL NATURAL MICROFLORA

Participants: Morris Mast
S. Poores
Jeong-Weon 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 MegaRads was determined best for use in later studies.

Doctoral Thesis:

"Effect of Three Defeathering Systems on the Morphology of Turkey Skin as Related to Attachment of Salmonella typhimurium," Kim, Jeong-Weon, Food Science, Dr. S. Poores, advisor. (In progress)

Paper:

"Infuence of Three Defeathering Systems on Morphology of Turkey Skin as Related to the Adhesion of Salmonella typhimurium," Kim, J. W., M. G. Mast and S. Poores, Oral Presentation at Annual Conference of IFT (Institute of Food Technologists) on June 2, 1991.

Sponsor: Pennsylvania Department of Agriculture, $66,198

Geosciences Department

FE ISOTOPIC ABUNDANCES USING NEUTRON ACTIVATION

Participants: Lee R. Kump
Gregg Bluth

Services Provided: Neutron Irradiation and Laboratory Space

We are developing new techniques to measure the relative abundances of the stable iron isotopes using NAA. Thus far we have been able to demonstrate significant and replicable differences in the $^{54}Fe/^{58}Fe$ ratio among high purity materials. Presently we are refining our prepurification steps to improve the precision of the measurement of natural, geologic materials. We will perform a survey of natural abundances, and then begin a study of the isotopic fractionation mechanisms. The initial study will focus on microbial iron reduction in saltmarsh sediments.

Sponsor: National Science Foundation, $13,406

Geosciences Department

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

Participants: David Eggler
Steve Shank
Lee 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 distinguished 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:

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

Sponsor: National Science Foundation

Horticulture

IRRADIATION OF COLOR POINSETTIA ACCESSIONS

Participants: Richard Craig
Andrew Riseman

Services Provided: Gamma irradiation

Tried to induce color mutants in commercial poinsettia cultivars. Currently evaluating material; will flower plants in December.

Metals Science & Engineering

NON-DESTRUCTIVE REACTOR MATERIALS EMBRITTLEMENT MONITORING FOR PLANT LIFE EXTENSION (PLEX) APPLICATIONS.

Participants: M. P. Manahan
Paula D. Freyer

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

Reactor pressure vessels and core internals are neutron irradiated during operation and consequently are subject to radiation-induced embrittlement. It is therefore 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 component steels using positron annihilation spectroscopy. 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 quantitication 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, much of the microstructural characterization of the unirradiated steel has been completed and work continues on the irradiated steel. TEM has been used to investigate the various phases and precipitates present in the unirradiated steel and electron diffraction patterns are currently being analyzed in order to identify these phases. SEM has been used to study the fracture surfaces of both the unirradiated and irradiated material. The positron lifetime measurements have also been completed and data deconvolution has been initiated.

Master's Thesis:

"Non-Destructive Reactor Materials Embrittlement Monitoring for Plant Life Extension (PLEX) Applications," Freyer, Paula D., Metals Science & Engineering, M. P. Manahan, advisor. (In progress)

Talks:

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

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

Nuclear Engineering

CHANGES IN MECHANICAL PROPERTY OF BORATED STAINLESS STEEL IRRADIATED WITH NEUTRONS

Participants: A. Baratta
M. Manahan
J. He
S. E. Soliman
K. Rudy

Services Provided: Neutron Irradiation, Radiation Counters, Machine Shop, Flux Monitoring and Electronics Shop

Borated stainless steel is utilized by the nuclear power industry in the shipment and storage of spent fuel. The boron in the stainless steel is used as a neutron absorber to prevent inadvertent criticality. Neutrons from the fuel are absorbed by the boron-10 isotope in an (n,a) reaction.

This project examines the effect of neutron irradiation on the mechanical properties of this material. The principle concerns are the embrittlement caused by fast neutron induced damage and the helium production from the boron-10 reaction.

Presently, a variety of samples were irradiated to different fluences. Some of these have undergone mechanical testing and microscopic examination. Current emphasis is on the properties of borated stainless steel which has been fabricated into spent fuel storage channels. Also, work is underway to evaluate the Kie fracture toughness of the material.

Masters Thesis:

"Fracture Toughness of Borated Stainless Steel," He, J., Nuclear Engineering, M. P. Manahan, advisor. (In progress)

Publication:

"Neutron Effects of Borated Stainless Steel," Solimon, S.E., D. L. Youchison, A. J. Baratta and T. A. Balliette, Nuclear Technologies (to be published 1992).

PERTURBED ANGULAR CORRELATION STUDIES OF NON-DOPED AND Ca-DOPED BARIUM TITANATE

Participants: Gary L. Catchen
James M. Adams
Robert L. Rasera

Services Provided: Neutron Irradiation and Angular Correlations Lab

To explore the range of phenomena that could be measured via nuclear electric quadrupole interactions in ferroelectric ternary metal oxides, Perturbed Angular Correlation (PAC) measurements were made on Ca-doped barium titanate at laboratory and elevated temperatures, and on non-doped barium titanate at cryogenic temperatures.

Ca-doped and non-doped polycrystalline samples of barium titanate were prepared using the resin-intermediate process. The Ca-doping was performed 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 $0 \leq y \leq 0.05$. In addition, all of the samples were doped with approximately 0.1 at. percent of Hf, which substituted into the Ti sites and carried the $^{181}Hf/^{181}Ta$ PAC probe radioactivity. The interactions measured on the Ca-doped samples can be explained by a simple random substitution model, in which the effects of Ca-doping are attributed to substitution of Ca^{2+} ions into the Ba-sites that are nearest to the probe sites. Out of this series of experiments, one result is particularly noteworthy. Paraelectric ABO_3 perovskites such as $SrTiO_3$, $BaHfO_3$ and $BaTiO_3$ (above T_c) should show no perturbations, because their structures have nominal cubic symmetry that should cause the efgs at the B sites to vanish. Instead these compounds show weak low frequency perturbations that traditionally have been attributed to the effects of O vacancies. The low-frequency perturbation that the 2-at.-percent-Ca-doped sample showed in the paraelectric phase was approximately twice as strong as the corresponding weak perturbation that the non-doped sample showed over the same temperature range. This result strongly suggests that O vacancies do not cause these featureless perturbations observed in these paraelectric phases. Instead these weak perturbations may arise from the effects of anharmonic, multiple-minima potentials at the Ti site. The interactions measured at cryogenic temperatures on non-doped barium titanate show an anomalous temperature dependence in the orthorhombic phase and the absence of a static interaction in the rhombohedral phase. the perturbation functions measured in the rhombohedral phase over the temperature range from 10 K to 150 K show exponential decay, which is the experimental signature of a time-varying interaction. The rate of this decay decreases as temperature increases. This trend suggests that a heretofore unknown nuclear-spin-relaxation mechanism is operative at low temperatures.

Publication:

"Perturbed Angular Correlation Studies of Ferroelectrics," Catchen, G. L. and R. L. Rasera, Ferroelectrics (in press).

Paper:

"Perturbed Angular Correlation Studies of Ferroelectrics," Catchen, G. L. and R. L. Rasera, presented at the workshop on Fundamental Experiments in Ferroelectrics, Williamsburg, VA, February 3-5, 1991 (invited paper)

Nuclear Engineering

EXPLORATORY INVESTIGATION OF NUCLEAR QUADRUPOLE INTERACTIONS IN A Hf-DOPED NiAl ALLOY

Participants: Gary L. Catchen
Donald A. Koss

Services Provided: Neutron Irradiation and Angular Correlations Lab

A structural material that we investigated is one member of the family of Ni_xAl_y alloys. This particular alloy offers the potential to provide a high strength-to-weight ratio, but currently this particular family of alloys lacks ductility. It is far too brittle to make any structural components out of. The ductility of this alloy depends on the concentration of dopants such as Hf, for example, as well as on the particular defect structure of a specific alloy. We made the preliminary measurements on a sample of NiAl doped with 0.1 atomic percent of Hf. We found that the $^{181}Hf/^{181}Ta$ probe can be used to measure nuclear quadrupole interactions in this alloy. The measured interactions indicate that the lattice is disordered, but considerably more work is needed to arrive at more definitive conclusions.

Nuclear Engineering

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

Participants: Gary L. Catchen
Clive A. Randall
David M. Spaar
Stephen J. Wukitch
James M. Adams
Robert 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 h 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:

"Temperature Dependence of the Ti Site Electric-Field Gradient in Titanite $CaTiSiO_5$," Catchen, G. L., C. A. Randall and R. L. Rasera, submitted to the Physical Review B, August 1991.

Nuclear Engineering

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

Participants: Gary L. Catchen
David 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. % Hf 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 extend 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:

"Unusual Linebroadening Temperature Dependence Associated with Nuclear Quadrupole Interactions in $LiNbO_3$ and $LiTaO_3$," Catchen, G. L., D. M. Spaar and ! D. Williams, 93rd Annual Meeting & Exposition of the American Ceramic Society, Cincinnati, OH, April 28-May 2, 1991.

Publication:

"Order-Disorder Effects in the Phase Transitions of $LiNbO_3$ and $LiTaO_3$ Measured by Perturbed-Angular-Correlation Spectroscopy," Catchen G. L. and D. M. Spaar, submitted to the Phys. Rev. B, June 1991.

Sponsor: Office of Naval Research $45,000

CHARACTERIZATIC:N OF SEVERAL FERROELASTIC, RARE-EARCH NIOBATE CERAMICS USING PERTURBED ANGULAR CORRELATION SPECTROSCOPY

Participants: Gary L. Catchen
David M. Spaar

Services Provided: Neutron Irradiation and Angular Correlations Lab

Perturbed Angular Correlation (PAC) Spectroscopy was used to measure nuclear electric quadrupole interactions in several polycrystalline, ferroelastic, rare-earth niobate ceramics. The study focused on $NdNbO_4$ and $GdNbO_4$, although some measurements were made on $YbNbO_4$ and $CeNbO_4$. The resin-intermediate method was used to prepare the samples. The $^{181}Hf/^{181}Ta$ probe was substituted into primarily the niobium sites at concentrations of 1.0 and 0.1 atomic percent of Hf. The resulting samples were characterized by x-ray powder diffraction and for the most part were found to be phase pure.

The samples were measured from 77 K to 1160 K, which included the monoclinic -to-tetragonal phase transition temperatures. The measurements on samples that were doped at 1 percent did not yield perturbation functions that could be characterized by unique parameters. However, the measurements on the samples doped at 0.1 percent did yield well-defined interactions. These perturbation functions yielded electric field gradients (efgs) and asymmetry parameters that showed anomalous minima and maxima, respectively. This variation indicated that the structural change of the compounds was consistent with second-order phase transitions. Most of the $^{181}Hf/^{181}Ta$ probes substituted into either defective or non-defective Nb-sites. Because the number of probes at non-defective sites increased with temperature, oxygen vacancy migration away from the probe sites may have occurred.

The results of these experiments show that the $^{181}Hf/^{181}Ta$ probe can be used successfully to study the efgs at chemically dissimilar lattice sites in ternary metal oxides containing Nb.

Master's Thesis:

"Characterization of Several Ferroelastic, Rare-Earth-Niobate Ceramics Using Perturbed Angular Correlation Spectroscopy," Spaar, D. M., 1991, Nuclear Engineering G. L. Catchen, advisor.

Publication:

"Highly Asymmetric Electric Field Gradients at the Nb-Sites in Ferroelastic $GdNbO_4$ and $NdNbO_4$," Catchen, G. L., I. D. Williams, D. M. Spaar, S. J. Wukitch and J. M. Adams, Physical Review B 43, pp. 1138-1141, 1991.

Paper:

"Highly Asymmetric Electric Field Gradients at the Nb Site in Ferroelastic $GdNbO_4$ and $NdNbO_4$," Catchen, G. L., I. D. Williams, D. M. Spaar, S. J. Wukitch and J. M. Adams, 93rd Annual Meeting & Exposition of the American Ceramic Society, Cincinnati, OH, April 28-May 2, 1991.

Nuclear Engineering

ANALYSIS OF THE FERROELECTRIC PEROVSKITE POTASSIUM NIOBATE BY PERTURBED ANGULAR CORRELATION SPECTROSCOPY

Participants: Gary L. Catchen
Stephen J. Wukitch

Services Provided: Neutron Irradiation and Angular Correlations Lab

Perturbed-Angular-Correlation (PAC) spectroscopy was performed on the ferroelectric perovskite potassium niobate, $KNbO_3$, using the $^{181}Hf/^{181}Ta$ probe. The samples prepared by the adapted resin-intermediate process were doped with 0.1 at. % of Hf that carried the $^{181}Hf/^{181}Ta$ probe. Phase-pure $KNbO_3$ ceramic samples were produced using this method, but significant precautions had to be taken to prevent the samples from reacting with water and carbon dioxide. Nuclear-electric-quadrupole interactions were measured from 295 K to 769 K, and the interactions were assumed to be measured at the Nb-sites. The electric field gradients associated with the $KNbO_3$ phase transitions were expected to be similar to those observed in barium titanate, $BaTiO_3$. However, the measurements yielded some results that were inconsistent with this expectation. The paraelectric cubic phase of $KNbO_3$ gave an experimental perturbation function that differed significantly from those measured by others on the cubic phase of $BaTiO_3$. But, the measurements on the orthorhombic structure yielded a relatively constant EFG in magnitude, which was similar to those observed by others on the two low-temperature phases of $BaTiO_3$. The measurements on the orthorhombic structure were characterized by the anticipated large asymmetry values. Measurements on the tetragonal and cubic structures, however, revealed significant asymmetry values that within experimental error were expected to be zero. The temperature dependence of the line broadening parameter, δ, was also found to be anomalous. The measurements on the high temperature phases should have showed small δ-values, but the measurements on these tetragonal and cubic phases showed large δ-values. Future PAC measurements of $KNbO_3$, which would include several experimental refinements, could possibly produce more detailed insight on the fundamental nature of crystal defects and structural phase transformations in this material.

Bachelor's Thesis:

"Analysis of the Ferroelectric Perovskite Potassium Niobate by Perturbed Angular Correlation Spectroscopy," Wukitch, S. J., 1990, Nuclear Engineering, G. L. Catchen, advisor.

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 and desorption kinetics at elevated temperatures in materials of interest to the tritium-processing industry.

Doctoral Thesis:

"An Experimental Study of the Distribution of Recoil-and Diffusion-charged Tritium in Metals," Dulloo, A. R., Nuclear Engineering, W. Diethorn, advisor. (In progress)

Paper:

"Radioassay Techniques in the Study of Tritium Contamination of Metals," Dulloo, A. R, ANS Student Conference (PSU), Spring 1990.

Sponsor: Mound Laboratory, third year

Nuclear Engineering

TRIGA REACTOR OPTIMAL CONTROL

Participants: Robert Edwards
James Turso
Dan Hughes
Mac Bryan

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

A Bailey Network 90 Distributed Control System is being used to implement advanced control strategies on the TRIGA. The secondary control rod drive (SCR) which travels in the central thimble, has been connected to a Bailey multifunction controller. In addition to the standard control functions of the multifunction controller, the capability to program additional controller algorithums via the "C" programming language is also available

Using the point kinetics equations (along with the appropriate TRIGA parameters) and thermal hydraulic theory (for fuel temperature calculations), a simulation has been developed using ACSL (Advanced Continuous Simulation Language). This in turn was used to develop and implement an optimal control strategy, state feedback assisted control, on the TRIGA. State Feedback Assisted Control (SFAC) consists of a state feedback controller (with the feedback gains "optimally" determined to give a desired fuel temperature response) sending a remote setpoint to a "classical," proportional controller. This arrangement is essentially a classical controller cascaded off of an optimal controller.

The experimental setup, consisting of the secondary control rod drive motor and SCR, was developed by the reactor facility staff.

The experiment consists of a reactor operator bringing the TRIGA up to 700 kw. At this power, with the SCR fully withdrawn from the core, reactor control is given to the Bailey system. A step change in demand (a negative 50 kw step) is introduced. The reactor response (i.e. power, modified demand sent from the optimal controller, fuel temperature, etc.) is observed and recorded.

At present, two experiments have been run with increasingly better results. Several changes have been made to the controller accordingly. A third experiment is scheduled.

Paper:

"Experience with Developing a Real-World Advanced Control and Diagnostic Testbed Using a University Research Reactor," Turso, J., R. Edwards, D. Hughes and M. Bryan, to be presented at the ANS AI91 conference, September 1991, Jackson, Wyoming.

Nuclear Engineering

NEUTRON ATTENUATION MEASUREMENTS OF BOROFLEX

Participants: D. Hughes
D. Kline
D. Vonada
K. Linquist

Services Provided: Neutron Irradiation, Neutron Instrumentation and Beam Lab

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

Sponsor: Northeast Technology Corporation $2500

Nuclear Engineering

TESTING OF A CONCEPT FOR ENVIRONMENTAL MONITORING OF AIRBORNE CARBON-14 AND TRITIUM ACTIVITY RELEASED FROM NUCLEAR POWER PLANTS

Participants: William A. Jester
Khalid M. Alam

Services Provided: Laboratory Space and Machine Shop

This research project is based upon the collection of carbon dioxide and water vapor from air. 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 system is in the final stages of completion.

Doctoral Thesis:

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

Sponsor:	FERMI	$15,000
	Pennsylvania Power and Light	$25,000

Nuclear Engineering

STUDY OF THE EFFECTS OF FISSION PRODUCT TELLURIUM ON THE IODINE SOURCE TERM UNDER SEVERE LIGHT WATER REACTOR ACCIDENT CONDITIONS

Participants: William A. Jester
Byung-soo Lee

Services Provided: Radiation Counters, Laboratory Space and Isotope Production

To study the effect of fission product tellurium on the species of radioiodine and its release rate. An experiment was conducted using tellurium compound which was neutron-activated in the TRIGA reactor. Some typical reactor containment surface materials, i.e., paint and stainless steel strips, were used to deposit tellurium compounds, which were dissolved and then the resulting airborne radioiodine species were sampled while the tellurium was decaying on the surfaces. Then iodine filters were gamma counted by a GeLi detector system for quantitative analysis.

Nuclear Engineering

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: William A. Jester
Samuel H. Levine
Manho Chung
Tzyy-Jye Lin

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

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. Initial measurements using ^{60}Co, ^{204}Tl and $^{90}Sr/^{90}Y$ sources under different conditions show good agreement with E13RO2 calculations.

Sponsor: Pennsylvania Power & Light Company

Nuclear Engineering

BETA DOSIMETRY PROJECT

Participants: William A. Jester
Samuel H. Levine
Manho Chung

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

The purpose of the research is to develop improved ways to compute 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.

Doctoral Thesis:

"Research and Development of a Beta Skin Dose Monitor Using Silicon Detectors," Chung, M., Nuclear Engineering, W. A. Jester and S. H. Levine, advisors. (In progress)

Publication:

"Development of a Beta Skin Dose Monitor Using a Silicon Detector," Chung, M., W. A. Jester and S. H. Levine, IEEE Transitions on Nuclear Science 38, No. 4 (accepted), August 1991.

Sponsor:	FERMI	$22,326.00
	Duquesne Light Company	$25,000.00
	GPU Nuclear Corporation	$15,000.00

Nuclear Engineering

PIPE WALL THINNING NDT USING X-RAY SCATTER

Participants: Edward S. Kenney
X. Xu

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

Pipe wall thinning is a serious problem in the secondary system of PWR's. Accidents have killed several workers when pipes exploded. This project seeks to demonstrate an NDT tool for measuring pipe wall thickness using gamma ray scatter. Progress to date includes Monte Carlo simulations and experiments using Cs-137 gamma rays and lower energies. The simulation work has led to construction of a proto-type gauge using Ir-192 gamma rays

Doctoral Thesis:

"A High Speed Wide-Aperture Compton Scatter Imaging Technique - A Computational Study with Application to Pipe Wall Thinning," Lee, Houlung, 1991, Nuclear Engineering, E S. Kenney, advisor.

Sponsor: FERMI $25,000

Nuclear Engineering

CHANGES EFFECTED IN WOOD AND WOOD PULP BY IRRADIATION

Participants: D. Kline
D. Vonada
D. Raupach

Services Provided: Gamma Irradiation and Laboratory Space

Pennsylvania has an exceptionally large hardwood timber industry. Wood usage somewhat exceeds the use of synthetic polymers, and it is the subject of a significant research effort. At PSU much of the research is carried out at the Forest Resources Lab.

Irradiation of wood and pulp has been carried out at the PSBR as an adjunct for research to try to understand physical property changes and to explore methods by which the properties can be modified and enhanced.

Nuclear Engineering

PROPERTIES OF THE NEUTRON ABSORBER MATERIAL BORAFLEX

Participants: D. Kline
D. Vonada
D. Raupach

Services Provided: Neutron Irradiation and Laboratory Space

Boraflex is a composite polymer of polysiloxanes with a B_4C-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 B_4C-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

THE EFFECTS OF RADIATION ON EUTECTIC METAL ALLOYS USED AS TEMPERATURE MONITORS

Participants: M. P. Manahan
Ha Cheung

Services Provided: Neutron Irradiation, Hot Cell Lab, Radiation Counters, Laboratory Space, Machine Shop, Flux Monitoring and Electronics Shop

Eutectic Metal Alloys are used today to monitor the temperature in pressure vessel surveillance capsules in nuclear power plants. It has been seen that these monitors indicate incorrect temperatures with increasing fluence.

This project was to see whether neutron irradiation on these materials would cause the false indications.

The monitors indicate the temperature by melting. Since neutron bombardment enhaces vacancy motion and these materials are alloys, it is conceivable that the imputity atoms may come out of solution leaving in the general mass, a different composition. Hence, this would change the melting temperature of the alloys.

Senior Honor's Thesis:

"The Effects of Radiation on Eutectic Metal Alloys Used as Temperature Monitors," Cheung, Ha, 1991, Engineering Science and Mechanics, M. P. Manahan, advisor.

Paper:

"The Effects of Radiation on Eutectic Metal Alloys Used as Temperature Monitors," Cheung, Ha, talk at the student ANS Regional Conference, University of Florida, March 1991.

Nuclear Engineering

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

Participates: M. P. Manahan
Jianhui He
Anthony Baratta

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

This purpose of the project is to perform experiment test and analysis of mechanical properties of several series of borated stainless steels manufactured by Carpenter Technology Corporation, with the specimens in both unirradiated and irradiated conditions. The main application of these steels is to make channel box to store spent fuel rack assemblies. It is a concern that neutron irradiation may embrittle the material. This study wi[illegible]monstrate the effect and make corresponding recommendations for the intended application.

Currently, tensile properties of unirradiated specimens have been investigated. Sections of life-size channel boxes have been compressed and studied. Most of the planned irradiation of tensile samples, compact tension samples and channel box sections have been performed. The experimental part of the project is about halfway done.

Sponsor: Carpenter Technology

Nuclear Engineering

NINE MILE POINT UNIT I 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 made by GE from Nine Mile Point Unit 1 nuclear power plant will be shipped to PSU and investigated in the hot cell laboratory. The main objective is to find the stress corrosion cracking (SCC) characteristics of the irradiated 304 stainless steel. Both non-

destructive and destructive testings will be performed. The theory employed in this project is H. Tada's stress intensity solution for double cantilever beam (DCB).

Master's Thesis:

"Nine Mile Point Unit I Stress Corrosion Cracking Sensor Postirradiation Examination," Yeh, T. K., Nuclear Engineering, M. P. Manahan, advisor. (In progress)

Sponsor: Niagara Mohawk Power Corporation

Nuclear Engineering

FACTORS AFFECTING SILVER AND CERIUM RETENTION IN BURN AND NORMAL SKIN

Participants: Dale Raupach
Quentin Hartwig
Harvey Slater

Services Provided: Neutron Irradiation and Radiation Counters

Despite extensive treatment, some severely burned patients die of multiple organ failure, the exact cause of which is still uncertain. Since the Cerium-Silver sulfadiazine is beneficial, investigation into the location of the silver and cerium in tissue would significantly improve the understanding of the manner in which these and other elements exhibit their antibiotic/antitoxic effects.

Neutron activation potentially stands as an ideal technic for assessing the quantities of silver, cerium and other elements in different tissues. Preliminary analyses are being conducted on excised samples of Silvadene cream treated burn tissues, some of which have had cerium added post excision.

Nuclear Engineering

AUTOMATED THERMAL POWER CALIBRATION TECHNIQUE FOR THE TRIGA REACTOR

Participants: M. H. Voth
K. Sahadewan
D. Hughes
M. 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 burnup.

The new calibration technique will improve upon the accuracy, sensitivity and reproducibility of the present method. Three different techniques were evaluated.

In the chosen technique, the core is isolated and the pool temperature is kept constant by controlling the flow through the heat exchanger. By keeping the pool temperature constant, heat losses due to convection and conduction are minimized and kept nearly constant.

Two-Terminal IC temperature transducers are connected to a Data Translation A/D card and 15 readings are monitored. The mass 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 using theoretical assumptions show that out of all possible sources of error, including losses through the pool wall, losses due to evaporation and uncertainties in measurements, flow rate and temperature readings have the biggest effect on the final result. The Magnetic Flow Sensor readings are accurate to ± 0.5% of reading plus ± 0.5% of full scale and the temperature transducers are sensitive to ± 0.01°C.

This technique is conveniently reproducible and we have proven that it is more accurate than the present method. It is being incorporated as one of the Reactor Operating Procedures (Checks and Calibrations Procedure - 2).

Master's Thesis:

> "Automated Thermal Power Calibration Technique for the TRIGA Reactor," Sahadewan K., Nuclear Engineering, M. H. Voth, advisor. (In progress)

Paper:

> "Automated Thermal Power Calibration Technique for the TRIGA Reactor," Sahadewan K., M. H. Voth, D. Hughes and M. Bryan, American Nuclear Society Eastern Regional Student Conference Transactions, University of Florida, March 1991.

<u>Physics Department</u>

THERMAL NEUTRON DIFFRACTION

Participants: P. Sokol
Mei Pang Fang
M. Guzzo
B. Sexton
F. Lany
M. Polashenski

Services Provided: Thermal Neutron Beam (Beam Lab)

This experiment is part of the Physics Department undergraduate/graduate laboratory and is intended to introduce the students to the basic principles of neutron scattering and to time-of-flight techniques. The experiment currently uses a beam of thermal neutrons from the neutron radiography beam line. The apparatus consists of a Fermi chopper, to create a pulsed beam, a ^{3}He proportional counter, an IBM-PC with multichannel analyzer card and associated electronics.

With this apparatus the students carry out two experiments:

1. Measurement of the velocity distribution of thermal neutrons from the reactor using time-of-flight technique.

2. Observation of Bragg scattering from a polycrystalline alummium sample.

The current setup is rather crude, consisting of a single detector and a simple drive system for the chopper. Funds provided by the NSF through the Instrumentation for Laboratory Improvement program will be used to upgrade the chopper drive electronics, add more detectors and increase the shielding for the apparatus.

Sponsor: NSF - Instrumentation for Laboratory Improvement - $20,000

Plant Pathology

BIOLOGY, MYCOTOXICOLOGY AND TAXONOMY OF FUSARIUM SPECIES

Participants: Paul E. Nelson
Jean Juba
Lois V. Klotz

Services Provided: Gamma Irradiation

Fusarium species were isolated from soil samples and soil debris obtained at altitudes of 1400, 1100, 800, 500, 250 and 0 m in the Republic of Transkei. Nineteen species of *Fusarium* were isolated representing sections *Eupionnotes*, *Sporotrichiella*, *Discolor*, *Gibbosum*, *Arthrosporiella*, *Liseola*, *Elegans*, *Martiella* and *Lateritium*. *Fusarium oxysporum*, *F. equiseti*, *F. semitectum*, *F. nygamai* and *F. solani* were isolated most frequently and *F. oxysporum* was the predominant species isolated from all samples. Other species recivered were *F. chlamydosporum*, *F. merismoides*, *F. lateritium*, *F. culmorum*, *F. compactum*, *F. dlamini*, *F. poae*, *F. proliferatum*, *F. moniliforme*, *F. graminerarum*, *F. sambucinum*, *F. napiforme* and three unknown populations. All species were grown on irradiated carnation leaf agar for identification. Using Simpson's index, the diversity indices calculated for *Fusarium* species from debris and soil from each sampling site indicate that overall debris was a greater source of species diversity than soil. Diversity indices calculated for each altitude sample and each isolation technique showed that the sea level site yielded the most diverse population.

Publication:

"Fusarium Species Isolated From Soil Samples Collected at Different Altitudes in the Transkei, southern Africa," Jeschke, N., P. E. Nelson and W. F. O. Marasas. Mycologia, 82, pp. 727-733, 1990.

PROCESSING EFFECTS ON PTC COMPOSITE THERMISTORS

Participants: Dr. Robert E. Newnham
Dr. James P. Runt
Robert J. Sullivan

Services Provided: Gamma Irradiation

The samples irradiated were V_2O_3-polystyrene composite positive temperature coefficient of resistance (PTC) thermistors. In these composites the V_2O_3 is dispersed throughout the polystyrene matrix. A PTC thermistor is a device which shows a large increase (5-8 orders) in resistance over a narrow temperature range (DT=20 C). The mechanism believed to be responsible for this anomaly in composite PTC thermistors is the expansion of the polymer matrix pulling the conductive particles apart. Gamma radiation induces crosslinking in the polystyrene matrix which decreases the thermal expansion. The greater the gamma dose the greater the resulting crosslink density and the less the thermal expansion of the polymer. As expected, the samples showed a decrease in the change in resistance with increasing gamma radiation. This decrease was attributed to the decrease in thermal expansion of the composite also seen with increasing radiation dose.

Doctoral Thesis:

"Processing Effects on PTC Composite Thermistors," Sullivan, Robert J., Solid State Science, Robert E. Newnham, advisor. (In progress)

Sponsor: Keystone Carbon Company - Ben Franklin Grant

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

University or Industry	Type of Use
Bettis Labs	Neutron Radiography
Bucknell University	Cobalt Irradiation
Burns Unit, Westpenn Hospital	Neutron Activation Analyses
Carpenter Technology	Neutron Radiography
Clarion University, Biology Department	Neutron Activation Analyses
Clarion University, School of Nursing	Neutron Activation Analyses
Cornell University	Neutron Activation Analyses
Emanco, Inc.	Neutron Activation Analyses
E-Systems	Semiconductor Irradiation
Fairway Laboratories	Environmental Analyses
GEC-Marconi	Semiconductor Irradiation
General Public Utilities	Californium Source Neutron Activation Analyses
Geochemical Testing	Environmental Analyses
Harris Semiconductor	Semiconductor Irradiation
Henry's Plant Farm	Cobalt Irradiation
Honeywell	Semiconductor Irradiation
Kearfott, Inc.	Semiconductor Irradiation
Merck, Sharpe and Dohme	Neutron Irradiation
Microbac Labs	Environmental Analyses
National Sanitation Foundation	Environmental Analyses
Niagara Mohawk	Neutron Radiography
Northeast Technology Corporation	Neutron Radiography
P. R. Hoffman Materials Processing Corp.	Cobalt Irradiation
Pennsylvania Power and Light Company	Environmental Analyses
Philadelphia Electric Company	Neutron Activation Analyses
Plessey-Marconi	Semiconductor Irradiation
Q. C. Inc.	Environmental Analyses
Raytheon	Semiconductor Irradiation
Seewald Laboratories	Environmental Analyses
State Museum of Pennsylvania	Neutron Activation Analyses
Tru-Tech	Isotopes for Tracer Studies
U.S. Department of Agriculture (Northeast Watershed)	Neutron Activation Analyses
Westpenn Hospital, Burns Unit	Neutron Activation Analyses
Wright Lab	Environmental Analyses

APPENDIX A

APPENDIX A

Personnel utilizing the facilities of the Penn State RSEC.

COLLEGE OF AGRICULTURE

Agronomy

Bollag, Jean-Marc
Professor

Ronen, Zeev
Graduate Student

Entomology

Hower, A.
Professor

Food Science

Beelman, Robert B.
Professor

Mast, Morris
Professor

Kim, Jeong-Weon
Graduate Student

Poores, S.
Assistant Professor

Horticulture

Craig, Richard
Professor

Riseman, Andrew
Graduate Student

Northeast Watershed Research Center

Barta, Susan
Hydrologist

Schnabel, Ron
Soil Scientist

Plant Pathology

Juba, Jean
Staff

Nelson, Paul E.
Professor

Klotz, Lois V.
Senior Research Aide

COLLEGE OF EARTH AND MINERAL SCIENCES

Geosciences

Bluth, Gregg
Graduate Student

Eggler, Dave
Professor

Greeman, Daniel J.
Graduate Student

Kump, Lee
Associate Professor

Rose, Arthur W.
Professor

Shank, Steve
Graduate Student

Washington, John W.
Graduate Student

Metals Science and Engineering

Freyer, Paula.
Graduate Student

Koss, Donald A
Professor

COLLEGE OF ENGINEERING

Engineering Science and Mechanics

Bakis, Charles
Assistant Professor

Bradford, Mark
Undergraduate Student

Gabrys, Jon
Undergraduate Student

Heinsohn, R. J.
Professor

Krick, John
Undergraduate Student

Lenahan, Patrick M.
Associate Professor

Industrial Engineering

Poeth, Dean
Graduate Student

Mechanical Engineering

Cimbala, John M.
Assistant Professor

Sathianathan, Dhushy
Graduate Student

Nuclear Engineering

Adams, James M.
Graduate Student

Kline, Donald
Professor Emeritus

Alam, Khalid
Graduate Student

Baratta, Anthony M.
Professor

Bonner, Joseph J.
Research Assistant

Boyle, Pat
Reactor Operator

Bryan, Mac E.
Electronic Designer

Catchen, Gary L.
Associate Professor

Cheung, Ha
Undergraduate Student

Chung, Manho
Graduate Student

Davison, Candace
Project Assistant

Diethorn, Ward
Professor

Dulloo, Abdul
Graduate Student

Edwards, Bob
Assistant Professor

Flinchbaugh, Terry L.
Operations & Training Manager

Ford, Bonnie C.
Supervisor, LLRML

Gould, Robert
Project Assistant

Hannold, Eric
Reactor Operator Intern

He, Jianhui
Graduate Student

Lee, Byung-soo
Graduate Student

Lin, Tzyy-Jye
Graduate Student

Levine, Samuel H.
Professor

Lu, Shanlai
Graduate Student

Manahan, Michael P.
Associate Professor

Raupach, Dale C.
Reactor Supervisor

Rudy, Kenneth
Operational Support Services
Supervisor

Sahadewan, Ken
Graduate Student

Sipos, Rick
Reactor Operator Intern

Soliman, Sahed E.
Post Doctoral

Spaar, David
Graduate Student

Turso, James
Graduate Student

Vonada, Douglas S.
Electronic Designer

Voth, Marcus H.
Associate Professor,
Director RSEC

Williams, James
Graduate Student

Wukitch, Stephen J.
Undergraduate Student

Xu, X.
Graduate Student

Hollinger, Edward
Undergraduate Student

Hughes, Daniel
Research Assistant

Jester, William A.
Professor

Kenney, Edward S.
Professor

Yeh, Tsung-Kuang
Graduate Student

Zarger, Michael
Graduate Student

COLLEGE OF LIBERAL ARTS

Anthropology

Sheehy, James J.
Graduate Student

COLLEGE OF SCIENCE

Biology

Thomas, Gene
Assistant Professor

Chemistry

Allcock, Harry R.
Professor

Ambrosio, Archel
Graduate Student

Benesi, A. J.
Lecturer

Coggio, W. D.
Graduate Student

Cizmecian, Deniz
Graduate Student

Dember, Alexa
Graduate Student

Fitzpatrick, Richard
Graduate Student

Jackman, Lloyd M.
Professor

Manners, I.
Post Doctoral Assistant

Nelson, Connie
Graduate Student

Pucher, Shawn
Graduate Student

Silverburg, Eric
Graduate Student

Turner, M. L.
Post Doctoral Assistant

Visscher, Karen
Graduate Student

Physics

Cuzzo, Mark A.
Undergraduate

Fosmire, Michael
Undergraduate Student

Lany, F.
Undergraduate Student

Mei Pang Fang
Graduate Student

Pilione, Lawrence J.
Professor

Polashenski, Mike
Undergraduate Student

Rank, Douglas
Undergraduate Student

Rosen, Nicholas
Graduate Student

Sexton, B.
Undergraduate Student

Sokol, Paul
Assistant Professor

INTERCOLLEGIATE RESEARCH PROGRAMS AND FACILITIES

Health Physics

Boeldt, Eric
Associate Health Physicist

Granlund, R. W.
University Health Physicist

Hollenbach, Donald H.
Health Physics Assistant

INTERDISCIPLINARY

Materials Research Lab

Randall, Clive
Research Associate

Solid State Science

Newnham, Robert E.
Professor, Chairman SSS

Runt, James P.
Associate Professor

Sullivan, Robert
Graduate Student

INDUSTRIES

Bettis Labs

Glickstein, Stan

Boston Edison Company

Green, William
Sheiver, Alan

Carpenter Technology

Balliett, Thomas

E Systems, ECI Division

Dobson, Robert
Miller, Darryl
Uber, Craig

Fairway Laboratories

Markel, William L. Jr.

Geochemical Testing

Bergstresser, Tim

Harris Semiconductor

Merges, John F.

Henry's Plant Farm

Nash, Jim

Honeywell

Collins, Dennis
Hildebrand, K.
Hoffman, Lee
Lintz, John
Parish, J.
Schuck, Carl

Kearfott

Breen, Larry
Brinkman, J.
Walendenski, W.

Merck, Sharpe and Dohme

Wurtz, Edwin

National Sanitation Foundation

Miller, Michael P.

Northeast Technology Corporation

Lindquist, Kenneth O.

Pennsylvania Power and Light

Hill, William A.

Philadelphia Electric Company

D'Angelo, Phil

Plessey-Marconi

Murtaugh, Stephen

P. R. Hoffman Materials Processing Corporation

Casey, Ken
Kingsborough, Lee

Q. C. Inc.

Stacer, Nancy

Raytheon

Berdos, P. L.
Black, B. W.
Callahan, K.
Christo, S.
Enriquez, G. J.
Johnson, B.
Johnson, R. B.
Mulford, S.
Poretsky, S.
Russell, R.
Shaw, R.
Schulz, P.
Stransky, D. F.

Seewald Laboratories

Chianelli, Robert E.

Tru-Tech

Boothe, Mike
Flanagan, Mike

Landry, Jeff

Westpenn Hospital, Burns Unit

Slater, Harvey

UNIVERSITIES

Hartwig, Quentin
Associate Professor
Clarion University

Tonzetich, John
Associate Professor, Biology
Bucknell University

Strom, Daniel J.
Professor of Health Physics
University of Pittsburgh

Rasera, Robert L.
Professor of Physics
University of Maryland

MISCELLANEOUS

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

APPENDIX B

APPENDIX B
FORMAL TOUR GROUPS

JULY 1990 JUNE 1991	DAY	NAME OF TOUR GROUP	NUMBER OF PARTICIPANTS
July	12	Kodak Best Program	26
	13	Soviet High School Students	31
	16	Alumni Tour	42
	27	See the Future	27
	30	Enter-2000	34
August	5	Penntap	5
	8	GPU Nuclear	20
	20	Incoming Nuclear Engineering Students	10
	30	Dr. Beelman's Class	27
September	7	PSU Alumni (Vlaminek Family)	8
	14	MBE Lab (Electrical Engineering)	6
October	1	Greensburg High School	11
	3	PSU Faculty Tour	6
	3	PSU Astronomy Club	9
	8	Peach Bottom Prof. Engr. Society	2
	8	University Scholars Program	11
	12	TRTR	14
	17	Antietam High School	42
	20	Open House - Parents' Weekend	152
	20	Museum Tour	29
	23	College of Engineering	5
	24	Warriors Mark Elementary	19
	25	College of Engineering	14
	25	Physics Society	6
	26	Williamson High School	39
	31	Materials Science 101	95
November	1	EG-50 Class	6
	5	Junior Science Symposium	15
	13	Punxsutawney High School	13
	13	Daniel Boone High School	15
	15	E&MS Interest House	15
December	18	Police Services Retraining	20
January	2	Police Services Retraining	18
	16	State College High School	25
	18	Jersey Shore High School	20
	25	Bucknell University	5
	29	Ligonier Valley Junior High School	115
February	1	State College High School	14
	7	Junior Museum - K. Sokol	15

APPENDIX B
FORMAL TOUR GROUPS
(Continued)

JULY 1990 JUNE 1991	DAY	NAME OF TOUR GROUP	NUMBER OF PARTICIPANTS
February	14	Entomology Class - Cobalt-60	5
	18	ETP- Group	4
	21	Society of Agricultural Engineers	13
	23	Engineering - Open House	343
	25	State College High School	33
	26	Bradford High School	37
	27	State College High School	17
March	1	State College - Todd McPherson	32
	12	Redland High School	20
	13	Bellefonte High School	19
	21	Twin Valley High School	28
	27	N. Bedford High School	8
April	3	Marion Center High School	7
	9	Wilkes College	2
	11	Suffern High School (April 12 continued)	10
	15	Physical Plant	9
	15	Cowanesque High School	31
	16	Physical Plant	12
	16	Secondary Saturday Science Academy	15
	16	STS Interest House	15
	17	Science Education	30
	18	Carmichaels High School	12
	19	Women in Engineering	6
	19	Cambria Heights	79
	23	Loyalsock High School	14
	25	Juniata College	5
	26	St. Mary's High School	24
	26	Ridgway High School	12
May	3	Chartiers-Houston High School	12
	8	Warren Area High School	18
	18	1991 Graduation Open House	60
	23	Organization Factors Workshop	32
June	19	GPU Nuclear Concepts	17
	24	High School Group	9
	27	RENEW (ECSEL)	26
	28	Upward Bound.	45
	29	Girl Scouts - Troop 45	8