PENNSTATE

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College of Engineering
Radiation Science and Engineering Center

Breazeale Nuclear Reactor Building
The Pennsylvania State University
University Park, PA 16802-2301

Annual Operating Report, FY 00-01
PSBR Technical Specifications 6.6.1
License R-2, Docket No. 50-5

December 20, 2001

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D. C. 20555

Dear Sir:

Enclosed please find the Annual Operating Report for the Penn State Breazeale Reactor (PSBR). This report covers the period from July 1, 2000 through June 30, 2001, as required by technical specifications requirement 6.6.1. Also included are any changes applicable to 10 CFR 50.59.

A copy of the Forty-Sixth Annual Progress Report of the Penn State Radiation Science and Engineering Center is included as supplementary information.

Sincerely yours,

C. Frederick Sears

C. Frederick Sears
Director, Radiation Science
and Engineering Center

Enclosures

tlf

cc. E. J. Pell
D. N. Wormley
L. C. Burton
E. J. Boeldt
M. Mendonca
T. Dragoun

A020

## PENN STATE BREAZEALE REACTOR

Annual Operating Report, FY 00-01
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 two 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 2500 visitors tour the PSBR facility each year.

RESEARCH/SERVICE 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.

The PSBR facility operates on an 8 AM - 5 PM shift, five days a week, with an occasional 7 AM - 7 PM or 8 AM - 12 Midnight shift to accommodate laboratory courses or research/service projects.

**Summary of Reactor Operating Experience -** Tech Specs requirement 6.6.1.a.

Between July 1, 2000 and June 30, 2001, the PSBR was

| | | |
|---|---|---|
| critical for | 864 hours | or 3.2 hrs/shift |
| subcritical for | 375 hours | or 1.4 hrs/shift |
| used while shutdown for | 424 hours | or 1.6 hrs/shift |
| not available | 108 hours | or 0.4 hrs/shift |
| Total usage | 1771 hours | or 6.6 hrs/shift |

The reactor was pulsed a total of 104 times with the following reactivities:

| | |
|---|---|
| < $2.00 | 10 |
| $2.00 to $2.50 | 77 |
| > $2.50 | 17 |

The square wave mode of operation was used 48 times to power levels between 100 and 500 KW.

Total energy produced during this report period was 472 MWH with a consumption of 24 grams of U-235.

**Unscheduled Shutdowns -** Tech Specs requirement 6.6.1.b.

The two unplanned shutdowns during the July 1, 2000 to June 30, 2001 period are described below.

October 4, 2000 – A reactor stepback occurred when the GIC Power Channel failed to respond during a startup to 700 kW. During a stepback the safety, shim and regulating rods are driven to their lower limits thus making the reactor subcritical. For reactor powers above 200 kW, the DCC-X control computer initiates a stepback when the power difference between the Wide Range Channel (neutrons) and Power Range Channel (gammas) is greater than 300 kw. An investigation revealed that the Power Channel's signal and high voltage cables had been pulled apart at their connections during a movement of the reactor tower on the previous day. Between then and the 700 kw startup leading to the stepback, the reactor had been operated at 3 kW (the GIC Power Channel does not respond at such a low power level so the cable disconnect was not noted). Operation of the reactor with the GIC Power Channel inoperative and its associated scram inoperative was a violation of Tech Specs and was reported as such.

February 26, 2001 – The reactor was scrammed by the reactor operator as per procedure when an experimenter reported that a rabbit capsule and sample had returned to the laboratory terminus without the rabbit capsule cap. An investigation revealed that the rabbit capsule cap had not been properly seated.

**Major Maintenance With Safety Significance -** Tech Specs 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 -** Tech Specs requirement 6.6.1.d.

Facility Changes -

On August 15, 2000, a new system was installed to improve the reactor operator's view of the Neutron Beam Laboratory. New cameras, monitors, controller and pan/tilt heads were installed. A staff review indicated that this change did not present any safety issues related to the SAR.

On November 27, 2000, a new Uninterruptable Power Supply (UPS) was installed to increase reliability over the previous UPS. The UPS provides power to the control console and associated equipment. A staff review indicated that this change did not present any safety issues related to the SAR.

On February 19, 2001, a diesel generator was installed to supply (during a loss of normal AC building power) a new emergency lighting system with lighted exit signs, and a new smoke detector and fire alarm system. Advantage was taken of excess generator capacity to provide additional AC backup power to the aforementioned UPS. A staff review indicated that this change did not present any safety issues related to the SAR.

Procedures -

Procedures are normally reviewed biennially, and on an as needed basis. Changes during the year were numerous and no attempt will be made to list them.

New Tests and Experiments -

None

**Radioactive Effluents Released -** Tech Specs requirement 6.6.1.e.

Liquid

There were no planned liquid effluent releases under the reactor license for the report period

Liquid radioactive waste from the radioisotope laboratories at the PSBR is under the University byproduct materials license and is transferred to the Radiation Protection 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

Gaseous effluent Ar-41 is released from dissolved air in the reactor pool water, air in dry irradiation tubes, air in neutron beam ports, and air leakage to and from the carbon-dioxide purged pneumatic sample transfer system.

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 Radiation Protection 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 359 mCi and 1088 mCi of Ar-41 is calculated for July 1, 2000 to June 30, 2001, resulting in an average concentration at ground level outside the reactor building that is 0.57 % to 1.73 % of the effluent concentration limit in Appendix B to 10 CFR 20.1001 - 20.2402. The concentration at ground level is estimated using only dilution by a 1 m/s wind into the lee of the 200 $m^2$ cross section of the reactor bay.

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 292 mCi. Since this production occurred in a stagnant volume of air confined by close fitting shield plugs, much 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; some of the Ar-41 releases from the tubes are part of rather than in addition to the release figures quoted in the previous paragraph. Even if all of the 292 mCi were treated as a separate release, the percent of the Appendix B limit given in the previous paragraph would still be no more than 2.1 %.

Production and release of Ar-41 from reactor neutron beam ports was minimal. Beam port #7 has only three small (1/2 inch diameter) collimation tubes exiting the port and any Ar-41 production in these small tubes is negligible. Beam port #4 has an aluminum cap installed inside the outer end of the beam tube to prevent air movement into or out of the tube as the beam port door is opened or closed. The estimated Ar-41 production in beam port #4 for all beam port operations is 35 mCi. With the aforementioned aluminum cap in place, it is assumed that this Ar-41 decayed in place. Radiation Protection Office air measurements have found no presence of Ar-41 with the beam port cap in place.

The use of the pneumatic transfer system was minimal during this period and any Ar-41 release would be insignificant since the system operates with CO-2 as the fill gas.

Tritium release from the reactor pool is another gaseous release. The evaporation rate of the reactor pool was checked previously by measuring the loss of water from a flat plastic dish floating in the pool. The dish had a surface area of 0.38 $ft^2$ and showed a loss of 139.7 grams of water over a 71.9 hour period giving a loss rate of 5.11 g $ft^{-2}$ $hr^{-1}$. Based on a pool area of about 395 $ft^2$ the annual evaporation rate would be 4680 gallons. This is of course dependent upon relative humidity, temperature of air and water, air movement, etc. For a pool $^3H$ concentration of 48937 pCi/l (the average for July 1, 2000 to June 30, 2001) the tritium activity released from the ventilation system would be 867 μCi. A dilution factor of 2 x $10^8$ ml $s^{-1}$ was used to calculate the unrestricted area concentration. This is from 200 $m^2$ (cross-section of the building) times 1 m $s^{-1}$ (wind velocity). These are the values used in the safety analysis in the reactor license. A sample of air conditioner condensate a previous year showed no detectable $^{3}H$. Thus, there is probably very little $^{3}H$ recycled into the pool by way of the air conditioner condensate and all evaporation can be assumed to be released.

| | |
|---|---|
| $^{3}H$ released | 867 μC |
| Average concentration, unrestricted area | $1.37 \times 10^{-13}$ μCi/ml |
| Permissible concentration, unrestricted area | $1 \times 10^{-7}$ μCi/ml |
| Percentage of permissible concentration | $1.37 \times 10^{-4}$ % |
| Calculated effective dose, unrestricted area | $6.9 \times 10^{-5}$ mRem |

**Environmental Surveys** - Tech Specs requirement 6.6.1.f.

The only environmental surveys performed were the routine TLD gamma-ray dose measurements at the facility fence line and at control points in two residential areas several miles away. This reporting year's measurements (in millirems) tabulated below represent the July 1, 2000 to June 30, 2001 period.

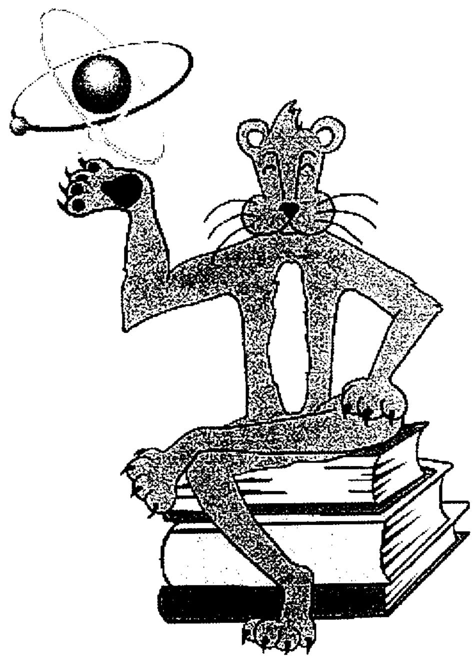
| | 3rd Qtr '00 | 4th Qtr '00 | 1st Qtr '01 | 2nd Qtr '01 | Total |
|---|---|---|---|---|---|
| Fence North | 28.7 | 27.1 | 44.5 | 25.9 | 126.2 |
| Fence West | 26.9 | 23.8 | 37.5 | 25.9 | 114.1 |
| Fence East | 28.6 | 29.3 | 40.1 | 25.7 | 123.7 |
| Fence South | 27.4 | 26.0 | 39.4 | 25.5 | 118.3 |
| Control | 26.1 | 25.9 | 43.2 | 25.9 | 121.1 |
| Control | 16.9 | 20.4 | 42.4 | 22.7 | 102.4 |

**Personnel Exposures** - Tech Specs requirement 6.6.1.g.

No reactor personnel or visitors received an effective dose equivalent in excess of 10% of the permissible limits under 10 CFR 20.

# The Pennsylvania State University

# Radiation Science and Engineering Center



# 46th Annual Progress Report

College of Engineering
Breazeale Nuclear Reactor
University Park, PA

December 2001

# FORTY-SIXTH ANNUAL PROGRESS REPORT

# PENN STATE RADIATION SCIENCE AND ENGINEERING CENTER

July 1, 2000 to June 30, 2001

Submitted to:

United States Department of Energy

and

The Pennsylvania State University

By:

C. Frederick Sears (Director)
Susan K. Ripka (Editor)
Radiation Science and Engineering Center
The Pennsylvania State University
University Park, PA 16802

December 2001

Contract DE-AC07-94ID-13223
Subcontract C88-101857
U.Ed.ENG 02-48

*Penn State is an affirmative action equal opportunity university.*

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# PREFACE

Administrative responsibility for the Radiation Science and Engineering Center (RSEC) resides in the College of Engineering. Overall responsibility for the reactor license resides with the 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 Pennsylvania State University Radiation Science and Engineering Center's Forty-Sixth Annual Progress Report (July 2000 through June 2001) is submitted in accordance with the requirements of Contract DE-AC07-94ID-13223 between the United States Department of Energy and Bechtel (BWXT Idaho), 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 dedication and commitment in this report, especially Sue Ripka who edited the report. 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 X.

# INTRODUCTION

# I. INTRODUCTION

## MISSION

It is the mission of The Penn State Radiation Science and Engineering Center in partnership with faculty, staff, students, alumni, government, and corporate leaders to safely use nuclear technology to benefit society through education, research, and service.

## VISION

Our unique facility has a diverse and dedicated staff with a commitment to safety, excellence, quality, customer satisfaction, and education by example. It is the vision of the faculty and staff of the Radiation Science and Engineering Center to be a leading national resource and make significant contributions in the following areas:

Safety—Actively promote safety in everything we do.

Education—Further develop innovative programs to advance societal knowledge through resident instruction and continuing education for students of all ages and their educators throughout the nation.

Research—Expand leading edge research that increases fundamental knowledge and technology transfer through our diverse capabilities.

Service—Expand and build a diverse array of services and customers by maintaining excellence, quality, customer satisfaction, and efficient service to supplement income and enhance education and research.

In conducting this mission in pursuit of the stated vision, the following activities are highlighted among the numerous accomplishments reported in the pages that follow:

- Numerous high school and non-PSU college/university groups participated in educational programs at the RSEC under the direction of Candace Davison during the year. In many cases, experiments teaching nuclear concepts were performed. The RSEC also supported educational events such as Boy Scout and Girl Scout merit badge programs. A complete list of groups hosted is presented in Appendix B.

- Reactor utilization continued at a high level. Grams of U-235 fuel consumed was the highest of anytime during the last decade..

- The relocation of the safety channel gamma detector to the rear of the reactor core has provided a better detector response. Refinements to the thermal power calibration procedure continued. In part as a result of the above, the reactor was returned to 1 MW operation.

- The irradiation of semi-conductors for commercial, military and space applications continued at a very healthy pace with several new users of our fast neutron irradiation facilities.

- The use of neutron radioscopy and neutron transmission as a research and service tool to industry became well established during the year with increasing interest by companies who fabricate boron containing metals used in the nuclear industry. Drs. Jack S. Brenizer and John M. Cimbala of the Mechanical and Nuclear Engineering Department continued a major research project using radioscopy for a Bettis Atomic Power Laboratory project involving fluid dynamics. A new project for a pharmaceutical company involved the radiography of drug delivery medical implant prior to clinical trials. A new neutron beam lab camera system for remote monitoring by the reactor operator was added.

- An automatic sample changer is now operational in the Radionuclear Applications Laboratory (RAL). This completed an upgrade of the laboratory begun the previous year with the purchase of new computers and Gamma Vision software. The user friendly software and auto sample changer have increased staff productivity and offer similar benefits to campus users.

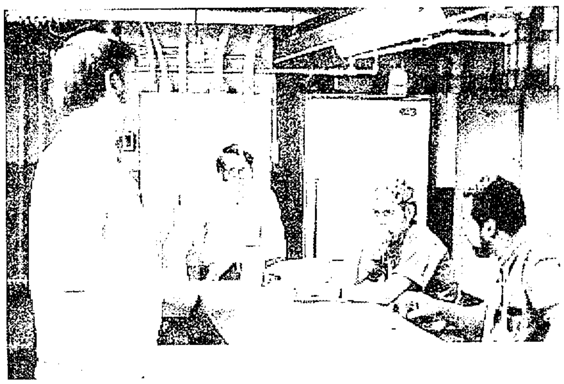
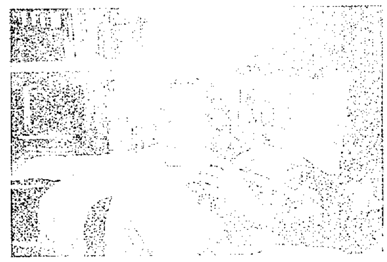
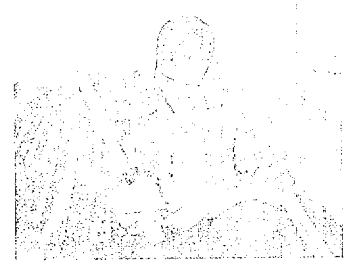
- Phase II of Dr. Robert Edwards' DOE funded project "Monitoring and Control Research Using a University Research Reactor" was completed. This involved considerable staff efforts in interfacing Dr. Edwards' control system with the Penn State thermal-hydraulic test loop.

- There was a significant increase in the number of samples irradiated, types of experiments and use of the Gamma Irradiation Facility. The number of sample hours in the GammaCell irradiator increased almost sevenfold and there was a 50% increase in the sample hours in the pool irradiator. Most of the irradiations are for university departments other than Mechanical/Nuclear Engineering.

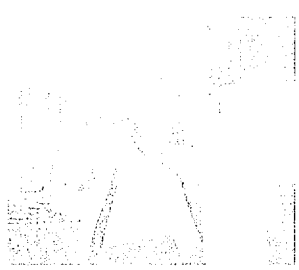
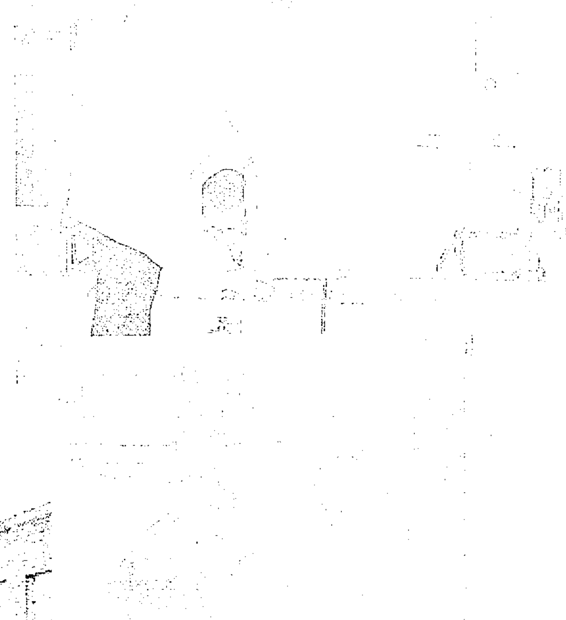
- Facility service income has supplemented university funds to address facility maintenance needs and upgrades. A major enhancement this year was the addition of a storage building to relieve facility space problems. A new uninterruptible power supply (UPS) for critical reactor equipment replaced an order unit. The service income allowed for the upgrade of calibration equipment used by the electronics repair shop, equipment purchases for the machine shop, an increase in spare parts inventory, and changes to improve facility appearance.

- The university's Office of Physical Plant (OPP) was responsible for some major modifications to the facility this past year. A new state-of-the-art fire detection system and emergency lighting system was installed in the entire facility. A new diesel generator was installed to provide back-up power to these systems. OPP was also responsible for overhauling all of the facility cranes.

- Facility safety upgrades continued with the facility and OPP sharing costs for the installation of new permanent roof ladders with safety cages, and the installation of safety cages on existing ladders.


# PERSONNEL

# II. PERSONNEL

Many students worked in work-study or wage payroll positions during the year. Jaclyn Adamonis, Jennifer Butler, Erin Carlin, Dianna Hahn, Kaydee Kohlhepp, Wayne Nixon and Tristan Schaefer assisted Candace Davison in facility educational programs for high school students. Shane Hanna served as a Neutronics Inspection Technician until the completion of his Masters Degree in May of 2001. Francis Buschman was hired to begin training as a reactor operator in August of 2000 and received his operator's license in June of 2001. Marcia Chesleigh assisted Dr. Brenizer on radiography projects during the year. Chanda Decker began work in May of 2001 performing various facility tasks with future plans of studying for an operator's license.

The following changes to the membership of the Penn State Reactor Safeguards Committee (PSRSC) were effective on January 1, 2001. Patrick Donnachie (Health Physicist, General Public Utilities) completed his second term on the committee and was not eligible for re-appointment. Randy Tropasso (Manager of Nuclear Design, Exelon) was appointed to the committee for a first term. Larry Hochreiter (Professor, Mechanical and Nuclear Engineering, Penn State) was re-appointed to a second term. Eric Boeldt was re-appointed to another three-year term (as Manager, Radiation Protection, Penn State, his service can be continuous).

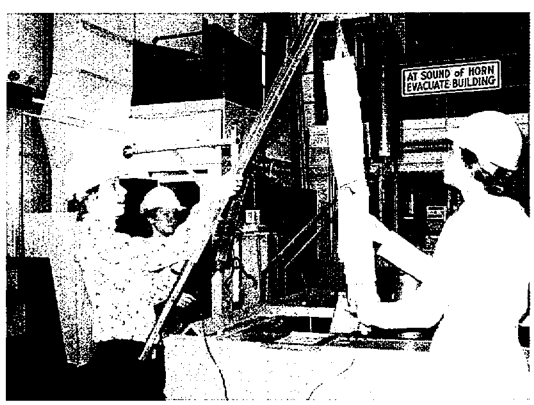



**Figure 1.** Tristen Schaefer and Jaclyn Adamonis assist Candace Davison (left front) in the Cobalt-60 Facility

## *TABLE I*

## Personnel

| | Faculty and Staff | Title |
|---|---|---|
| * | F. X. Buschman | Reactor Operator Intern |
| | J. S. Brenizer | Professor, Nuclear Engineering |
| ** | M. E. Bryan | Research Engineer/Supervisor, Reactor Operations |
| | G. L. Catchen | Professor, Nuclear Engineering |
| ** | T. H. Daubenspeck | Activation and Irradiation Specialist/Supervisor, Reactor Operations |
| ** | C. C. Davison | Research and Education Specialist/Supervisor, Reactor Operations |
| | W. R. Donley | Staff Assistant VI |
| ** | T. L. Flinchbaugh | Manager, Operations and Training |
| * | M. P. Grieb | Engineering Aide |
| ** | B. J. Heidrich | Research Assistant |
| ** | A. R. Portanova (formerly Helton) | Reactor Operator/Research and Service Support Specialist |
| | J. Lebiedzik | Research Support Technician III |
| ** | G. M. Morlang | Reactor Engineer/Supervisor, Reactor Operations |
| | J. Myers | Computer Support Specialist |
| | A. D. Pope | Staff Assistant V |
| | P. R. Rankin | Radiation Measurement Technician |
| | S. K. Ripka | Administrative Assistant II |
| | K. E. Rudy | Supervisor of Facility Services |
| ** | C. F. Sears | Director & Affiliate Associate Professor, Nuclear Engineering |
| ** | D. L. Werkheiser | Reactor Operator Intern |

* *Licensed Operator*
** *Licensed Senior Operator*

| Technical Service Staff | |
|---|---|
| R. L. Eaken | Machinist A |
| S. Thomas | Staff Support |

| Wage Payroll/Workstudy | |
|---|---|
| J. Adamonis | S. Hanna |
| J. Butler | K. Kohlhepp |
| M. Chesleigh | D. Hahn |
| E. Carlin | W. Nixon |
| C. Decker | T. Schaefer |

Penn State Reactor Safeguards Committee

| | | |
|---|---|---|
| | R. C. Benson | Professor and Department Head, Mechanical and Nuclear Engineering, Penn State |
| | E. J. Boeldt | Manager of Radiation Protection, Environmental Health and Safety, Penn State |
| | T. C. Dalpiaz | Manager, Nuclear Maintenance, Pennsylvania Power and Light Susquehanna Steam Electric Station |
| * | J. P. Donnachie, Jr. | Health Physicist, General Public Utilities |
| | A. Haghighat | Professor, Nuclear Engineering, Penn State |
| | L. Hochreiter | Professor, Mechanical & Nuclear Engineering, Penn State |
| | I. B. McMaster | Retired Deputy Director, Penn State Breazeale Nuclear Reactor |
| | G. E. Robinson | Professor Emeritus, Nuclear Engineering, Penn State |
| | D. Sathianathan, Chairman | Assistant Professor, Engineering Graphics, Penn State |
| | C. F. Sears | Ex-Officio, Director, Penn State Radiation Science and Engineering Center |
| ** | R. Tropasso | Manager of Nuclear Design, Exelon |

* *Served through January 1, 2001*

** *Appointed January 1, 2001*

# Radiation Science & Engineering Center Personnel Chart

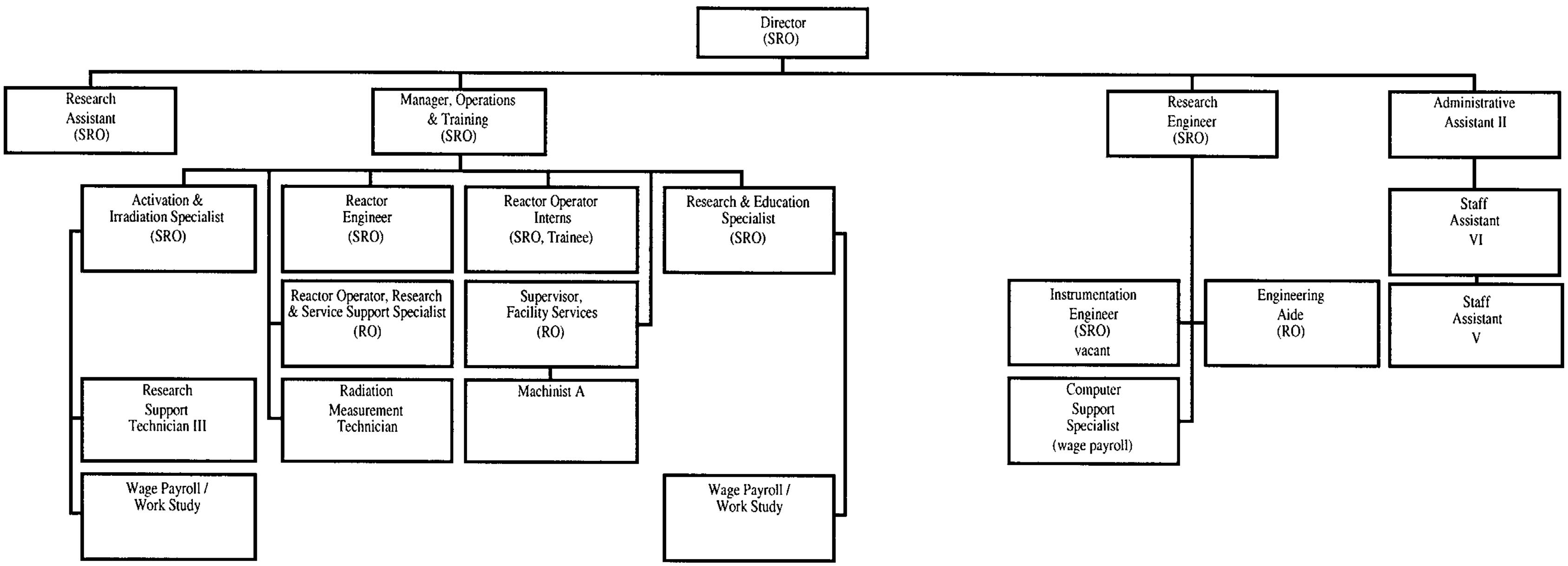



**Figure 1**

# REACTOR OPERATIONS

# *III. REACTOR OPERATIONS*

Research reactor operation began at Penn State in 1955. In December of 1965, the original 200 kW reactor core and control system was replaced by a more advanced General Atomics TRIGA core and analog control system. TRIGA stands for Training, Research, Isotope Production, built by General Atomic Company. The new core was capable of operation at a steady state power level of 1000 kW with pulsing capabilities to 2000 MW for short (milliseconds) periods of time.

In 1991, the reactor console system was upgraded to an AECL/Gamma-Metrics dual digital/analog control system. This system provided for improved teaching and research capabilities and features a local area network whereby console information can be sent to laboratories and emergency support areas.

Utilization of the Penn State Breazeale Reactor (PSBR) falls into four 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, non-destructive examinations of materials using neutrons or x-rays, or transient behavior of the reactor to the calibration of a reactor control rod.*

Research -- *involves Radionuclear Applications, Neutron Radiography, Gamma Irradiation, a myriad of research programs by faculty and graduate students throughout the University, and various applications by the industrial sector.*

Training -- *programs for PSBR Reactor Operations Staff.*

Service -- *involves Radionuclear Applications, Neutron Transmission Measurements, Radioscopy, Semiconductor Irradiations, Isotope Production and other applications by the industrial sector.*

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 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. A pneumatic transfer system offers additional possibilities. A heavy water tank and neutron beam laboratory provide for neutron transmission and neutron radioscopy activities. Core rotational, east-west, and north-south movements provide flexibility in positioning the core against experimental apparatus.

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

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

Support facilities include hot cells, a machine shop, electronic shop, darkroom, 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.

**Figure 1. Brenden Heidrich, Research Assistant**

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

The Number of Scrams Planned as Part of Experiments reflects experimenter needs. Unplanned Scrams from Personnel Action are due to human error. Unplanned Scrams Resulting from Abnormal System Operation are related to failure of experimental, electronic, electrical or mechanical systems.

Table 3, Part A, Reactor Usage, describes total reactor utilization on a shift basis. The summation of Hours Critical and Hours Subcritical gives the total time the reactor console key is on. Hours Shutdown includes time for instruction at the reactor console, experimental setup, calibrations or very minor maintenance that occupies the reactor console but is done with the key off. Significant maintenance or repair time spent on any reactor component or system that prohibits reactor operation is included in Reactor Usage as Reactor Not Available.

Part B gives a breakdown of the Type of Usage in Hours. The Mechanical and Nuclear Engineering Department and/or the Reactor Facility receives compensation for Industrial Research and Service. 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, reflects the number of users, samples and sample hours per shift. Part D shows the number of eight hour shifts for each year.

### *INSPECTIONS AND AUDITS*

A routine NRC inspection was conducted by James Dwyer of NRC Region I on November 14-16, 2000. This inspection covered activities authorized by Penn State's Broadscope License, Cobalt Pool License, and Self-Contained Irradiator License. No items of non-compliance were identified.

A routine NRC inspection was conducted by Thomas Dragoun of NRC Non-Power Reactor Branch on June 11-15, 2001. This inspection covered activities authorized by Penn State's R-2 Reactor Licnese. No items of non-compliance were identified.

During October and November of 2000, an audit of the PSBR was conducted to fulfill a requirement of the Penn State Reactor Safeguards Committee charter as described in the PSBR Technical Specifications. The audit was conducted by Warren F. Witzig, retired Head of the Penn State Nuclear Engineering Department. The reactor staff implemented changes suggested by that report, all of which exceed NRC requirements.

*TABLE 2*

**Reactor Operation Data**
**July 1, 1998 - June 30, 2001**

| | | 98-99 | 99-00 | 00-01 |
|---|---|---|---|---|
| A. | Hours of Reactor Operation | | | |
| | 1. Critical | 895 | 941 | 864 |
| | 2. Subcritical | 396 | 455 | 375 |
| | 3. Fuel Movement | 17 | 46 | 0 |
| B. | Number of Pulses | 29 | 75 | 104 |
| C. | Number of Square Waves | 14 | 28 | 48 |
| D. | Energy Releases (MWH) | 365 | 419 | 472 |
| E. | Grams U-235 Consumed | 17 | 22 | 24 |
| F. | Scrams | | | |
| | 1. Planned as Part of Experiments | 9 | 11 | 11 |
| | 2. Unplanned - Resulting From | | | |
| | a) Personnel Action | 2 | 1 | 0 |
| | b) Abnormal System Operation | 7 | 1 | 1 |

## *TABLE 3*

**Reactor Utilization Data**
**Shift Averages**
**July 1, 1998 - June 30, 2001**

| | | 98-99 | 99-00 | 00-01 |
|---|---|---|---|---|
| A. | Reactor Usage | | | |
| | 1. Hours Critical | 3.3 | 3.4 | 3.2 |
| | 2. Hours Subcritical | 1.5 | 1.6 | 1.4 |
| | 3. Hours Shutdown | 1.5 | 1.9 | 1.6 |
| | 4. Reactor Not Available | 0.2 | 0.1 | 0.4 |
| | TOTAL HOURS PER SHIFT | 6.5 | 7.0 | 6.6 |
| B. | Type of Usage - Hours | | | |
| | 1. Industrial Research and Service | 3.4 | 3.2 | 3.4 |
| | 2. University Research and Service | 0.4 | 0.4 | 0.6 |
| | 3. Instruction and Training | 0.7 | 0.9 | 1 |
| | 4. Calibration and Maintenance | 1.9 | 2.3 | 1.6 |
| | 5. Fuel Handling | 0.1 | 0.2 | 0 |
| C. | Users/Experiments | | | |
| | 1. Number of Users | 2.4 | 2.7 | 2.6 |
| | 2. Pneumatic Transfer Samples | 0.1 | 0.1 | 0.3 |
| | 3. Total Number of Samples | 2.7 | 3.0 | 3.2 |
| | 4. Sample Hours | 2.8 | 3.0 | 2.9 |
| D. | Number of 8 Hour Shifts | 273 | 279 | 270 |

# GAMMA IRRADIATION FACILITY

# IV. GAMMA IRRADIATION FACILITY

The Gamma Irradiation Facility includes in-pool irradiators and a dry shielded GammaCell 220 irradiator. The Gamma Irradiation Facility is designed with a large amount of working space around the irradiation pool. This is where the GammaCell 220 is located along with workbenches and the usual utilities.

## In-Pool Irradiators

For the in-pool irradiators, the source rods are stored and used in a pool 16 feet by 10 feet, filled with 16 feet of demineralized water. The water provides a shield that is readily worked through and allows great flexibility in using the sources. Due to the number of sources 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. Four different irradiation configurations have been used depending on the size of the sample and dose rate required. The advantage of the in-pool irradiators is that the dose rate can be varied in a manner which is optimal for agricultural and life science research.

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, and the dose rates available are summarized in Table 4.

## GammaCell 220 Dry Irradiator

The GammaCell 220 dry irradiator has a dose rate considerably higher than that currently available in the RSEC in-pool irradiators. Other advantages of the GammaCell 220 include a large irradiation chamber (approximately 6 inches diameter and 7.5 inches high), an automatic timer to move the sample chamber away from the source and the ability to conduct in-situ testing of components during irradiation.

The David Sarnoff Research Center in Princeton, New Jersey donated the GammaCell 220 to Penn State in July of 1995. The maximum dose rate is summarized in Table 4.

## Use of Gamma Irradiation Services

There was a significant increase in the number of samples irradiated, types of experiments and use of the Gamma Irradiation facility. The number of sample hours in the Gammacell irradiator increased almost sevenfold and there was a 50% increase in the sample hours in the pool irradiator! Several departments on campus utilized the services of the Gamma Irradiation facility for a variety of purposes. Figure 2 shows some of the variety of samples and purposes for irradiations this past year. Table 5 compares the past three years' utilization of the Cobalt-60 Irradiation Facility in terms of time, numbers and daily averages.

# TABLE 4

| Summary of Current Gamma Irradiation Facilities | | |
|---|---|---|
| **Facility** | **Maximum Dose Rate in KRads/hour*** | **Sample Limitations** |
| North Tube 6-inch | 32.0 | Must be less than 6 inches in diameter |
| South Tube 3-inch | 55.1 | Must be less than 3 inches in diameter |
| 10-inch Chamber | 1.2 | Cylinder approximately 10 inches in diameter by 12 inches in height |
| GammaCell Dry Cell Irradiator | 210.8 | Cylinder approximately 6 inches in Diameter by 7.5 inches in height |
| *as of 7/1/2001 | | |

# TABLE 5

| Cobalt-60 Utilization Data July 1, 1998 – June 30, 2001 | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | **98-99** | **98-99** | **99-00** | **99-00** | **00-01** | **00-01** |
| | | **Pool Irradiator** | **GammaCell** | **Pool Irradiator** | **GammaCell** | **Pool Irradiator** | **GammaCell** |
| A. | Time Involved (Hours) | | | | | | |
| | 1. Set-Up/Admin. Time | 28 | 30 | 10 | 21 | 15 | 55 |
| | 2. Total Sample Hours | 1473 | 978 | 1040 | 563 | 1557 | 3800 |
| | | | | | | | |
| B. | Numbers Involved | | | | | | |
| | 1. Samples Containers Run[1] | 1644 | 287 | 742 | 383 | 542 | 615 |
| | 2. Different Experimenters | 12 | 17 | 17 | 23 | 12 | 21 |
| | 3. Configurations Used | 3 | NA | 3 | NA | 3 | NA |
| | | | | | | | |
| C. | Per Day Averages | | | | | | |
| | 1. Experimenters | 0.4 | 0.4 | 0.2 | 0.5 | 0.2 | 0.6 |
| | 2. Samples | 6.6 | 1.1 | 2.9 | 1.5 | 2.2 | 2.5 |
| | | | | | | | |

The sample hours for the GammaCell for 2000-2001 would be equivalent to over 25,000 sample hours in the large pool irradiation tube.

# Gamma Irradiation Uses and Examples

## Genetic Changes


Poinsettias

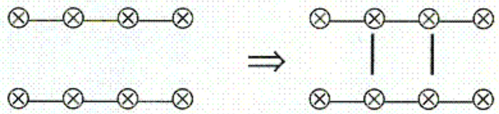

Fruit Flies


Cells


Amaryllis


Dogwood Tree Seeds

## Cross-Linking of Polymers



## Food Irradiation

Class Projects and Demonstrations:


Beef Patties


Pizza


Mushrooms


Salmon


Apples

## Sterilization

Medical & Laboratory Products

Soil & Leaves for Environmental Research

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# EDUCATION AND TRAINING

# V. EDUCATION AND TRAINING

During the past year, Penn State's RSEC was used for a variety of educational services, in-house training, formal laboratory courses, and many continuing education programs and tours. The continuing education programs and tours accommodated over 2,500 visitors.

## Operator Training:

The RSEC operating staff has maintained reactor operator competence and safe facility operation through training and requalification. During a two-year training cycle, theory, principles, regulations and actions needed for the safe operation of the reactor facility are covered. Training sessions during the year include lectures, exercises, and other activities. In-house reactor operator requalification during November of 2000, consisted of an oral examination on abnormal and emergency procedures given by C. C Davison and an operating test given by T. H. Daubenspeck. The written requalification exam was given by T. L. Flinchbaugh in January of 2001. Operator Intern Francis Buschman passed his NRC Reactor Operator License examination in June of 2001. Alison Portanova, a licensed reactor operator, passed her NRC Senior Reactor Operator License examination in June of 2001.

## Police Training:

In February of 2001, a total of 34 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.

## Governor's School:

The fifteenth session of the Pennsylvania Governor's School for Agricultural Sciences (PGSAS) was held at Penn State's University Park campus during the summer of 2000. Sixty-four high school scholars participated in the five-week program at Penn State. The Governor's School for Agricultural Sciences includes introduction and experience in many different agricultural disciplines. The participants of the Governor's School received a tour of the Reactor facility with some time for hands-on instruction. Candace Davison, Wayne Nixon and Kaydee Kohlhepp provided the instruction for the PGSAS tours.

## Reactor Sharing:

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.

Nearly 500 students and teachers from 22 different educational institutions and 4 colleges came to the RSEC for experiments and instruction (see map). Candace Davison, Kaydee Kohlhepp, Dianna Hahn, Wayne Nixon and Joseph Bonner were the main instructors for the program. Tristan Schaefer and Chanda Decker along with other Mechanical and Nuclear Engineering Students provided information about their major during student visits. Thierry Daubenspeck, Jana Lebiedzik, Mac Bryan, and Dr. Jack Brenizer provided instruction and technical assistance for experiments.

The RSEC staff utilized the facilities and equipment to provide educational opportunities and tours for student and teacher workshops, many of which were conducted as part of other programs on campus. These programs are typically conducted through the Penn State College of Engineering, the Women in Science and Engineering (WISE) Institute, the Continuing and Distance Education Program, Campus Admissions and the University Relations Offices. The student programs included: the VIEW program, Women in Science and Engineering (WISE) week, Girlz in Engineering, Upward Bound, Pennsylvania Junior Academy of Sciences and other programs associated with campus activities. Several different activities for Girl Scouts and Boy Scouts were conducted at the facility.

Job-shadowing was another means by which some pre-college students learned about nuclear applications. The students spent from half a day to several days shadowing staff and faculty at the facility to enhance their understanding of nuclear technology and careers.

## ***Nuclear Science & Technology Course***

A one-week course on Nuclear Science and Technology was conducted from July 30 through August 4, 2000. John Vincenti was the coordinator of the course which was held a second time based upon the success of the first course. Ten teachers attended the workshop and received free Geiger Counters through a grant from the American Nuclear Society. Candace Davison provided instruction on radiation, reactor basics, nuclear applications and conducted experiments at the facility for the participants.

## ***Tours:***

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 groups detailed in the above sections, who toured the facility are listed in Appendix B. The RSEC operating staff and Nuclear Engineering Department conducted several Open House events for the Parent and Family Weekend, the general public and potential undergraduate or graduate students. Over 500 people participated in Open House and "Spend a Day" experiences.

## ***Academic Instruction:***

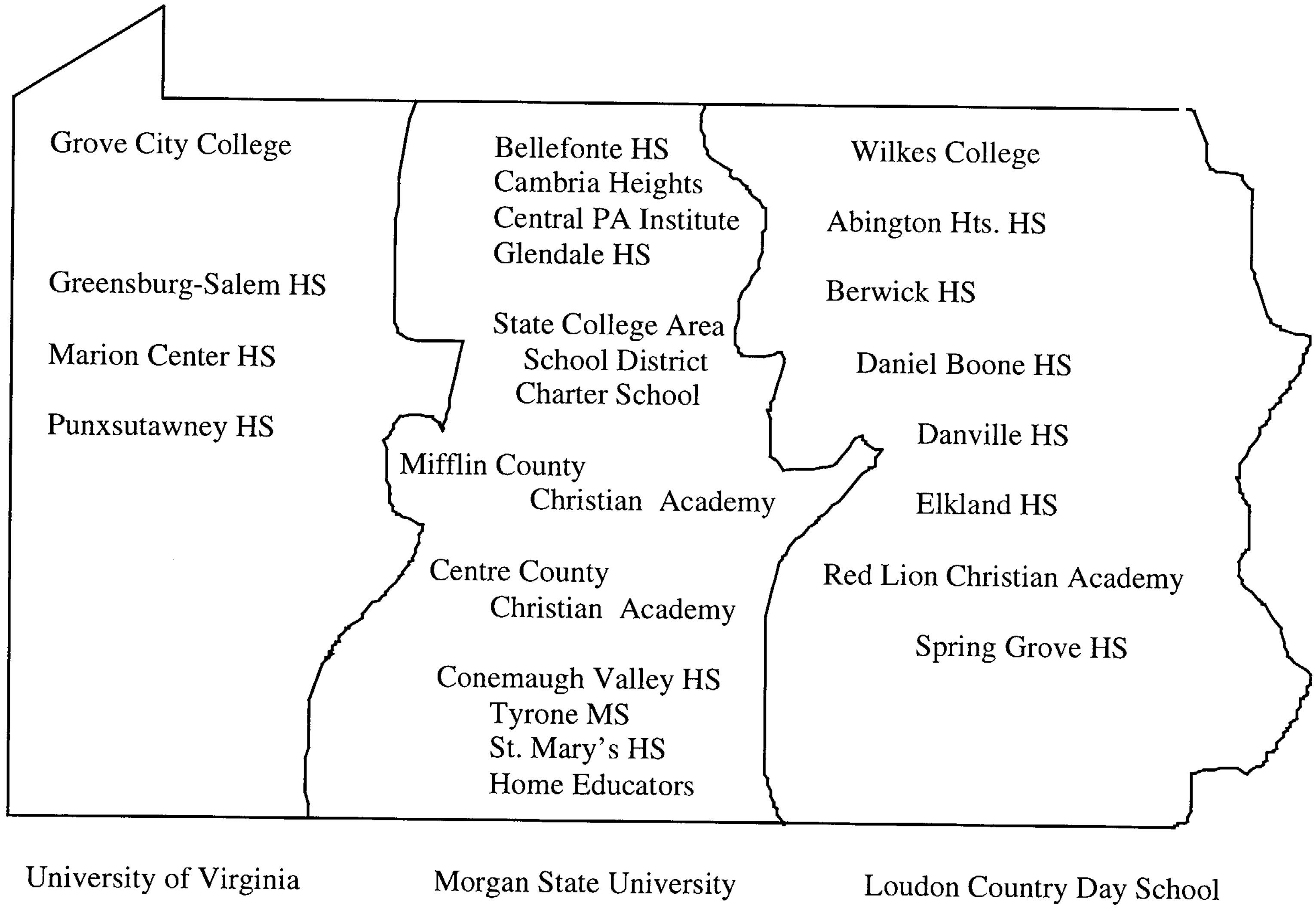
The RSEC supports academic instruction by providing information and expertise on nuclear technology topics, tours and experiments conducted at the facility and through the availability of specialized equipment and classroom/laboratory space.

A new venture this past year was a joint instructional experience for students in the IE 408W (Human Factors) course. The students were instructed on reactor basics so that they could understand the control signals and input. An overview of the control console was provided in the classroom with real-time signal input observation via the LAN and multimedia projector. The students then went into the control room where they observed a start-up and the operator's actions. They also observed the reactor while at power. Feedback from the students was very positive concerning their real-world experience. One student brought his family for a tour during graduation weekend.

The reactor classroom was utilized as the base of instruction for several courses including; Freshman seminar – ENGR 001 (Fall 2000 and Spring 2001), NUCE 450, NUCE 451, NUCE 597D, and NUCE 297/497. The TRIGA reactor and Cobalt-60 irradiation facilities were used by several Nuclear Engineering courses and courses in other departments of the university as outlined in the table below.

| Semester | | Course | Instructor | Students | Hours |
|---|---|---|---|---|---|
| Summer | 2000 | NucE 444 – Nuclear Reactor Operations | C. F. Sears | 1 | 19 |
| Summer | 2000 | SCIED 498B – Nuclear Science and Technology Workshop | J. R. Vincenti<br>C. C. Davison | 10 | 4 |
| Fall | 2000 | Nuc E 401 – Introduction to Nuclear Engineering | L. Hochreiter | 11 | 3 |
| Fall | 2000 | Engr 001 – Freshman Seminar | J. S. Brenizer | 4 | 3 |
| Fall | 2000 | NucE 451 – Reactor Physics | R. M. Edwards | 11 | 24 |
| Fall | 2000 | Food Science 413 – Science & Technology of Plant Food | R. B. Beelman | 21 | 2 |
| Fall | 2000 | Food Science /STS 105 | A. Harmon | 18 | 1 |
| Spring | 2001 | Engr 001 – Freshman Seminar | J. S. Brenizer | 4 | 3 |
| Spring | 2001 | NucE 444 – Nuclear Reactor Operations | C. F. Sears | 2 | 34 |
| Spring | 2001 | IE 408 W Human Factors | I. J. Petrick | 76 | 3 |
| Spring | 2001 | NucE 450 – Radiation Detection and Measurement | J. S. Brenizer | 15 | 5 |

# Educational Institutions Visiting the RSEC



# 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. Well-collimated beams of neutrons, thermalized by a $D_20$ thermal column, are passed into the NBL for use in nondestructive testing and evaluation. A neutron camera, by Precise Optics, Inc. is available for radioscopy (real time radiography). Equipment is available to digitize the real time radiography images for image processing. A photographic laboratory facilitates the development and analysis of static neutron radiographs. Flash radiography utilizing pulsing is also available.

A new $D_20$ thermal column to enhance the neutron beam for beam port #4 in the NBL was installed in April of 1997. This thermal column can take advantage of the extra degrees of freedom provided by the bridge upgrade completed in the Summer of 1994. The reactor core is coupled to the thermal column in a position tangential to the beam line thereby improving the neutron to gamma ratio. A significant increase in the neutron beam intensity has resulted. Characterization of the neutron beam continues. In early 1999, a new shield wall and shield roof were installed around beam port #4 to provide facilities for conducting neutron radioscopy, neutron radiography, and other research and service activities. That same year, the collimator was changed to improve the radiography characteristics of the beam. A 12.7-cm aperture is located adjacent to a bismuth gamma photon filter at the juncture of the port and the $D_2O$ thermal column. At a power of 500 kW, the neutron flux is $1.4 \times 10^7$ with an L/D ratio of 115, the $n/\gamma$ ratio is $3 \times 10^6$ n/cm2/mR, and the cadmium ratio measured with gold foils is 5. The facility meets the ASTM E-545 Category 1 requirements.

In October 1998, a collimator arrangement was installed to couple beam port #7 to the $D_20$ thermal column via a graphite scatterer. Two small diameter neutron beams are provided for conducting neutron transmission measurements of borated metals and other borated materials.

Projects utilizing the NBL during the year included the following:

- Bettis Atomic Power Laboratory used the RSEC beginning in June 2000, to evaluate the operational characteristics of an ammonia loop heat pipe.

Paul Rankin, Radiation Measurement Technician aligns heat pipe while Brenden Heidrich, Research Assistant and Marcia Chesleigh, Undergraduate Student observe.

- Neutron transmission measurements and neutron radioscopy were conducted for borated metals and other borated materials for Northeast Technology Corporation, Eagle-Picher Industries, Transnuclear, NY, Transnucleaire, France, and St. Louis Metallizing Company.

- Radiographic and radioscopic techniques were demonstrated as part of several student projects; including demonstration of neutron and x-ray imaging for the Governor's School students. The students assembled boxes containing a variety of objects and predicted their neutron & x-ray attenuation characteristics. Experiments with neutron & x-ray radiography confirmed their predictions.

- A pharmaceutical company used radiography to examine drug delivery medical implants prior to clinical trials.

- Work continued on an ASTM Divergence and Alignment Indicator (DAI) standard. This work resulted in a paper presented at the Fourth International Topical Meeting on Neutron Radiography.

# RADIONUCLEAR APPLICATIONS LABORATORY

# VII. RADIONUCLEAR APPLICATIONS LABORATORY

The Radionuclear Applications Laboratory (RAL) provides consulting and technical assistance to University personnel who wish to use radionuclear techniques in their research. The majority of these research projects involve neutron activation, but the staff is also able to provide services in radioactive tracer techniques, radiation gauging, radiation processing, and isotope production for laboratory, radionuclear medicine or industrial use. The RAL has continued to increase its gamma spectroscopy capabilities with the purchase of an automatic sample changer.

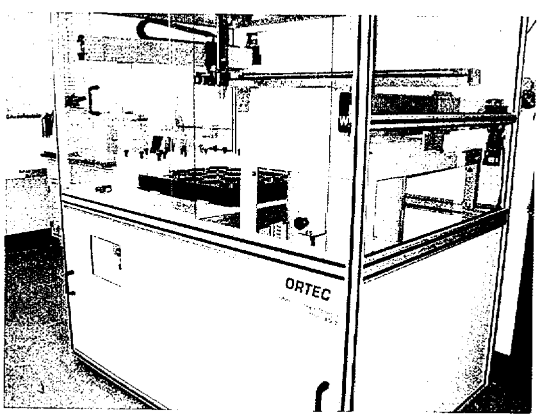


**Figure 1. Automatic Sample Changer**

In addition to providing analyses of environmental samples for alpha/beta and gamma activities, the RAL also performs analyses in support of the Breazeale Reactor's operations. Laboratory personnel support RSEC operations by performing analyses of water, air monitor filters, and other samples as needed.

These analyses include gross alpha/beta activity for the reactor pool water, Cobalt-60 pool water, the reactor facility's secondary heat exchanger water and tritium content analysis of reactor pool water. Gamma spectroscopy analysis is performed on these samples on a quarterly basis or as needed. The RAL also measures the tritium concentration in the Deuterium Oxide ($D_2O$) tank each month. The 6,000 gallon holding tank for the pool make-up water is analyzed once each year according to the Office of Radiation Protection requirements.

Last year, 465 semiconductor irradiations were performed at the RSEC for various companies. RAL personnel prepared devices for irradiation, calculated the 1-MeV Silicon Equivalent fluence received, and determined the radioisotopes produced in the devices. These devices were then returned to the companies in accordance with NRC and DOT regulations.

The facility performed 15 isotope production runs of Na-24, Br-82 or Ar-41 for industrial use during the past fiscal year. As needed, the RAL is able to analyze and test chemicals not currently on our approved list.

Penn State students and faculty members continue to use the services offered by the RAL. Analytical work was performed for graduate and undergraduate students in the Nuclear Engineering and the Anthropology departments. Nuclear Engineering students use the RAL for various projects that are being performed at the RSEC.

**Figure 2. Thierry Daubenspeck, Activiation and Irradiation Specialist, prepares a sample to be irradiated.**

The RAL assisted students from the Anthropology Department in characterizing various samples of obsidian and rhyolite using Neutron Activation Analysis (NAA). This analysis involves determining the concentrations of specific elements in various obsidian and rhyolite samples to identify the source of the samples. This is a continuation of work that began years ago.

The RAL is in the process of improving its capabilities by improving current systems or designing new systems to provide more versatility in reactor operations. The current argon production system is being improved which will result in a lower personnel exposures and shorter irradiation times.

The pneumatic transfer system (rabbit system) is currently being re-engineered to allow NAA work to be performed while operating at the Beam Port facilities. The current rabbit system does not permit the reactor to be simultaneously coupled with the Beam Port facilities.

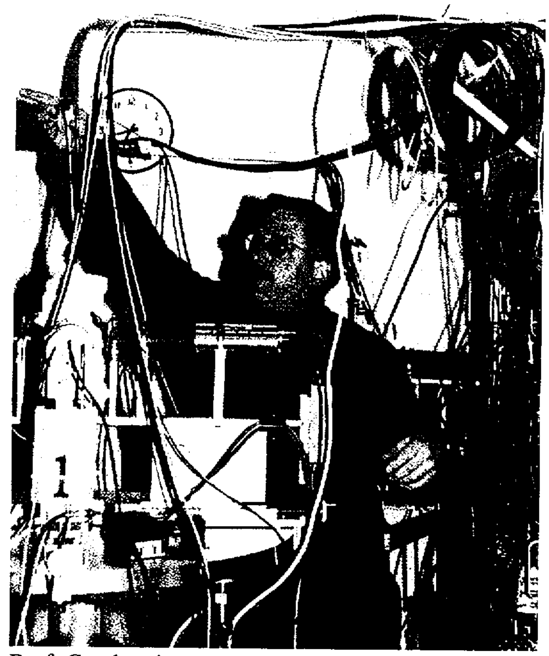
# THE ANGULAR CORRELATIONS LABORATORY

# VIII. THE ANGULAR CORRELATIONS LABORATORY

The Angular Correlations Laboratory has been in operation for approximately 14 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 three spectrometers for making Perturbed Angular Correlation (PAC) measurements. One apparatus, which has been in operation for 14 years, measures four coincidences concurrently using cesium fluoride detectors. A second spectrometer was acquired ten years ago, and it measures four coincidences concurrently using barium fluoride detectors. A third spectrometer was set up seven years ago to accommodate the increased demand for measurement capability. 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.

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. The National Science Foundation and the Office of Naval Research have sponsored this program in the past. Currently Professor Catchen is seeking funding to continue the research.

The PAC technique is based on substituting a radioactive probe atom such as $^{111}In$ 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 (efg's) and hyperfine magnetic fields produced by the extranuclear environment.



Prof. Catchen inserts a sample into a high-temperature sample furnace, which is mounted in the center of the four-detector array of the perturbed-angular-correlation spectrometer

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. In solids, these interactions can provide information about defect and ionic transport. In liquids these interactions can provide information about, for example, the conformations of macromolecules such as polymers. 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 or by molecules tumbling in a solution, 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 antiferromagnetic bulk and thin-film materials, are used to study the mechanisms that cause the transition between the magnetically-ordered phase and the disordered phase.

Current laboratory research is detailed in Section A of this report.


# LOW-PRESSURE INTEGRAL TEST FACILITY

# IX. LOW-PRESSURE INTEGRAL TEST FACILITY

## INTRODUCTION

The Penn State University Low-Pressure Integral Test Facility (LPITF) is a one-half height scaled representation of the General Electric's Simplified Boiling Water Reactor (SBWR). The unique characteristic of the facility is that it was designed, built, and engineered by Nuclear Engineering undergraduate students. The facility was started in 1995 with funding from the Dean of Engineering. Subsequent funding was obtained from different companies, such as Westinghouse, Rosemount-Fisher and others as well as matching funds from the Department of Energy. Penn State students participated in the scaling analysis used for the design, the hardware design, and fabrication of the facility components, analysis of the facility response, testing and analysis associated with the data. Figure 1 shows a simplified layout of the thermal-hydraulic test loop, LPITF, which shows the natural circulation flow path. The facility also includes the passive and active systems proposed on the preliminary design.

The facility is operated near atmospheric pressure such that transparent test sections can be used to show the flow and boiling behavior for different conditions.

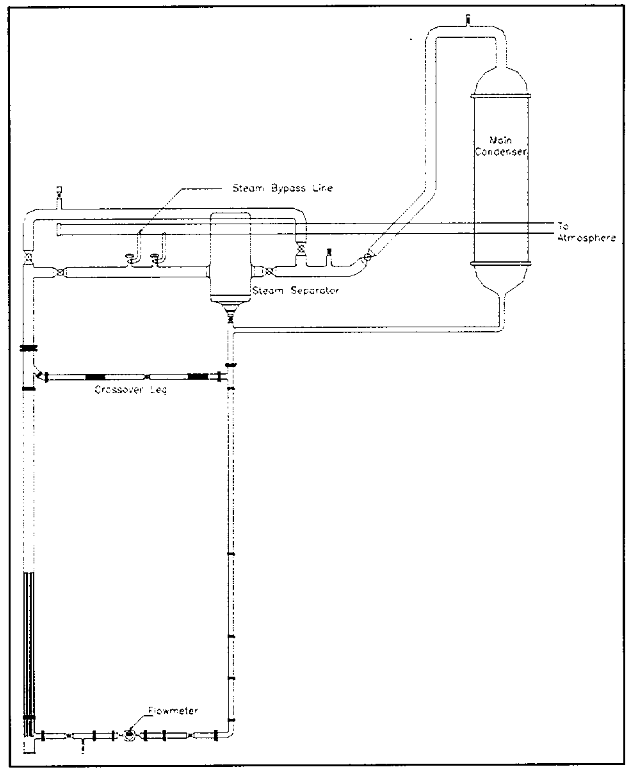



**Figure 1** – Simplified layout of the thermal-hydraulic test loop

## FACILITY COMPONENTS

The reactor core is simulated using 12, one-half height electric heater rods, as can be seen in Figure 2. Four rods have four embedded surface thermocouples each, which determine the temperature profile along the bundle. Additional heater rods have a thermocouple near the exit of the heated length. The heater rods are connected to silicon controlled rectifiers (SCR), which provide the electrical power to the rod bundle. The glass channel diameter is 3-inches, which was obtained by scaling the facility to the SBWR.

The core and the downcomer regions of the test loop are made of borosilicate glass so that the flow can be seen. This configuration allows students to visually study the boiling process and two-phase flow behavior over a range of thermal-hydraulic conditions. Figure 3 shows the front-view of the test loop. On the right hand-side of the picture is seen the core test section which is made of borosilicate glass. The penetrations through the core are for instrumentation such as pressure transducers, void probes, and thermocouples. Figure 4 is the core picture at a different angle and shows some instrumentation such as the flow meter, and an absolute pressure cell and a differential pressure cell across the heated bundle. The loop flow meter is located on the connecting leg between the core lower plenum and downcomer.

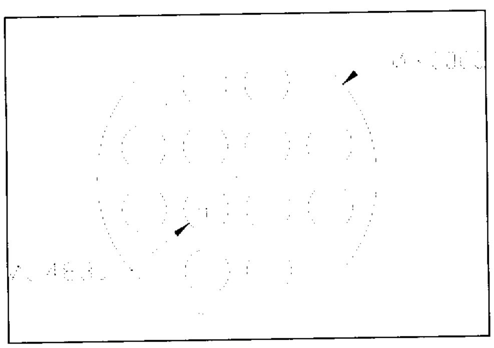


**Figure 2** – Core rod layout.

**Figure 3** – Front view of the test loop core section. The core is located on the basement of the Cobalt-60 irradiation facility.

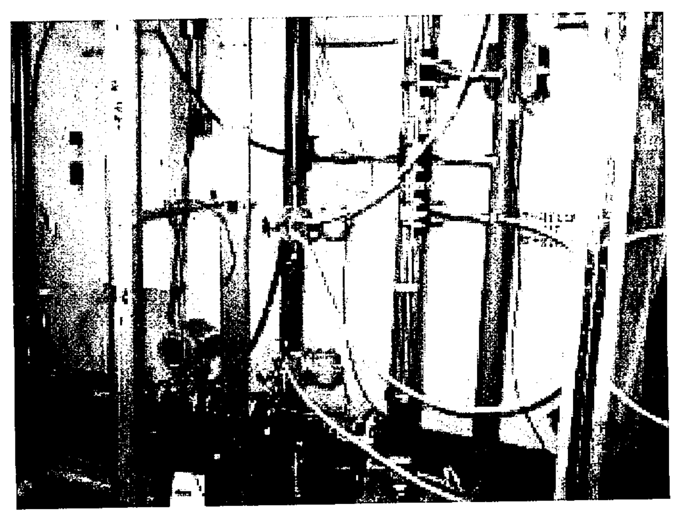


**Figure 4** – Angle-view of the core.

## INSTRUMENTATION

The behavior of the system can be determined from the various instrumentations, which are distributed along the flow loop.

The instrumentation in the facility includes:

1) Flowmeter: A very sensitive magnetic flowmeter; located on the pipe between the downcomer and heater rod bundle lower plenum.

2) Pressure transducers: Absolute and differential pressure measurements to estimate the average void fractions in two-phase flow.

3) Void probes: The miniature void probes penetrate into the piping and bundle, and determine the local void concentration at different locations.

4) Thermocouples: There are two different J-type thermocouples: surface thermocouples, which are inside the heater rods and measure the heater rod surface temperature; and fluid thermocouples, which measure the local fluid temperature. The computer hardware allows up to 64 simultaneous thermocouple connections.

5) Power transducers: The power applied through the SCR's is read back to verify electrical heat input.

The measurements from the instruments are collected on a computer and can be seen online by the use of an interface application designed in LabVIEW. This application also interfaces to control the power signal to SCR's, which in turn controls the heat input to the rods. The main control interface can be seen in Figure 5.

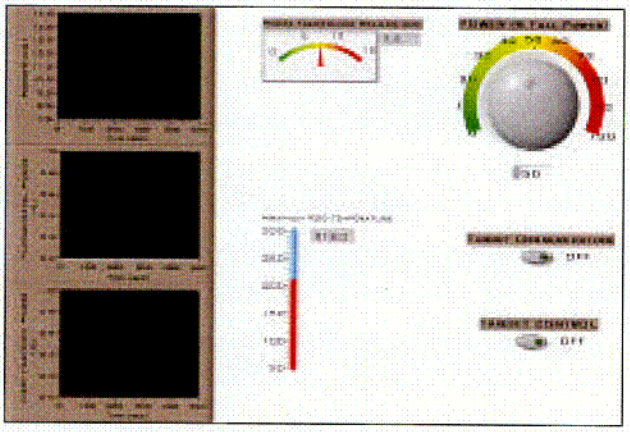


**Figure 5** – Screenshot from the LabVIEW main control interface.

## TYPES OF EXPERIMENTS

The main objective of the test loop is for students to understand the principles of single-phase and two-phase natural circulation flow and heat transfer behavior. The students determine energy balances over the system, and observe the two-phase natural circulation.

### Single-Phase Natural Circulation Experiments

During 2000-2001, single-phase experiments were performed in the spring. The students were requested to check the physical integrity of the facility, get acquainted with the instrumentation, and verify that the electrical energy transferred to the core matched the energy transfer in the primary side of the main condenser as well as the energy transfer in the secondary side of the main condenser. The students also developed calculational models to predict the natural circulation flow in the test



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loop. Calculations were also performed with the TRAC-PF-I code.

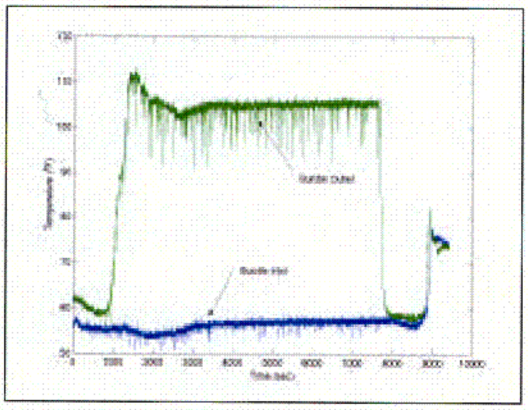

**Figure 6** – History of the core mean temperatures during a single-phase flow.

Figure 6 and Figure 7 show the fluid temperature behavior during the single phase natural circulation experiment along the core and in the main condenser. The flow becomes established as the temperature difference develops between the hot and the cold legs, as can be seen in Figure 8. The heater rod axial temperature distribution is shown in Figure 9 for this experiment.

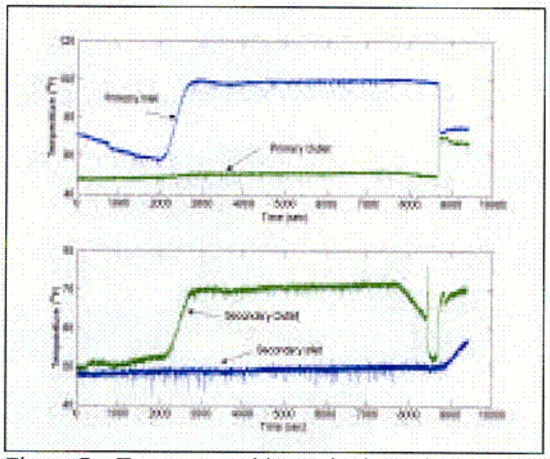

Figure 7 – Temperature history in the main condenser.

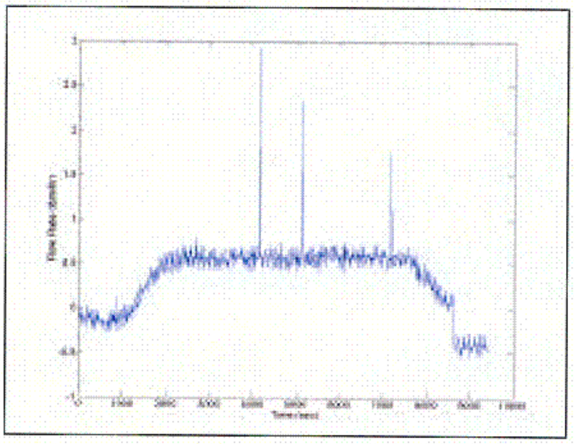

Figure 8 – Single-phase natural circulation flow rate.

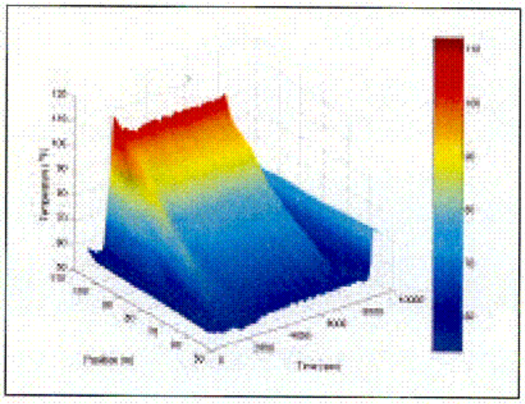

**Figure 9** – 3-D profile along the core of the fluid temperature for this particular experiment.



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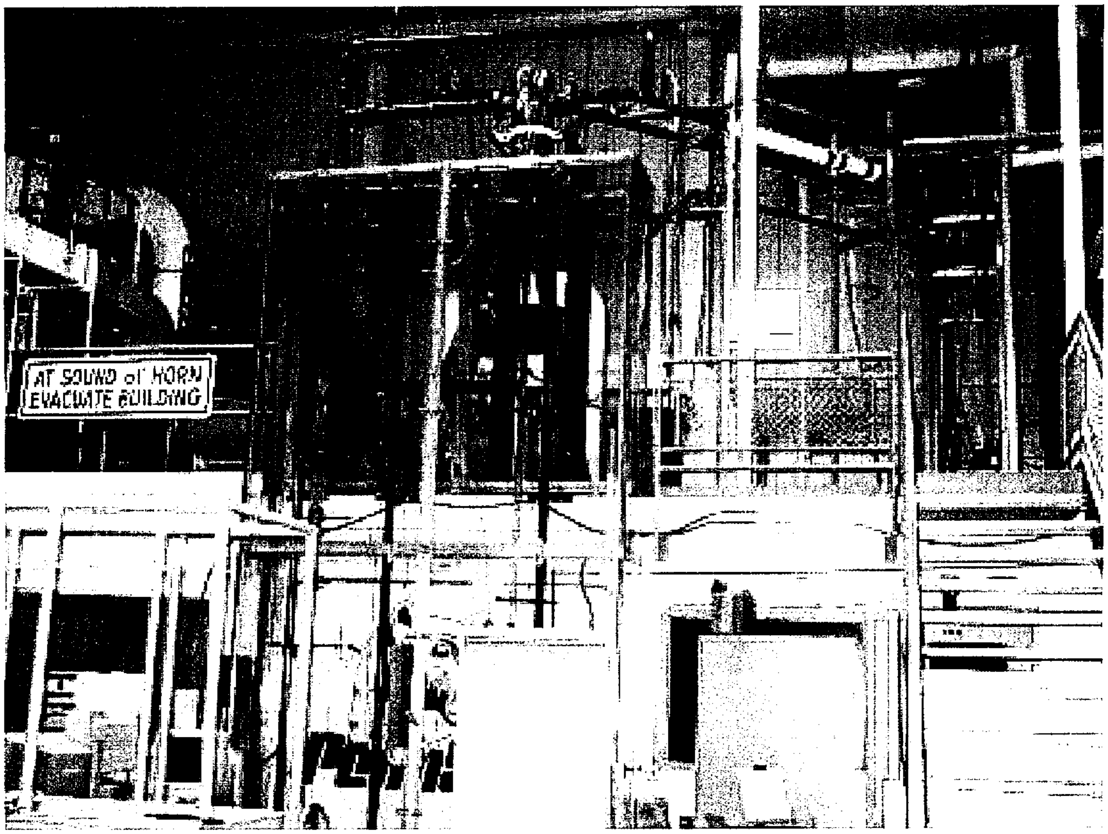


**Figure 12** – The riser, chimney sections of the core; crossover leg, and steam separator.

## CONCLUSIONS

The Penn State Low Pressure Integral Test Facility has proved to be a very effective learning tool for Nuclear and Mechanical Engineering students. This facility allows the students to gain "hands-on" learning experiences in design, fabrication, and thermal-hydraulic testing and analysis. It provides the students with an opportunity to observe the complex boiling and two-phase processes that occur in commercial light water reactors and other boiling systems.

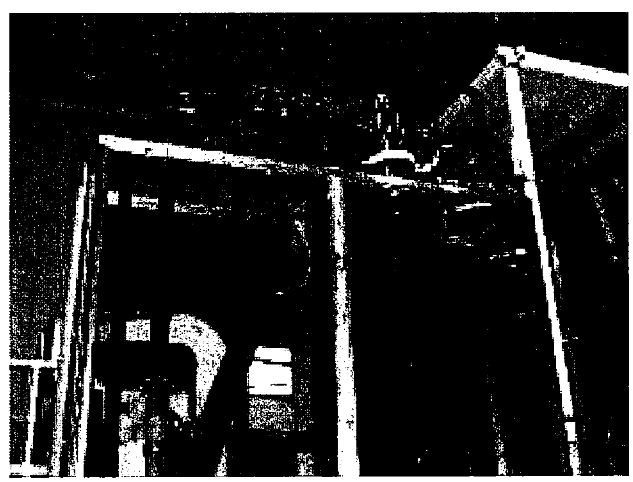


**Figure 13** – A closer look to the crossover leg and the steam separator.

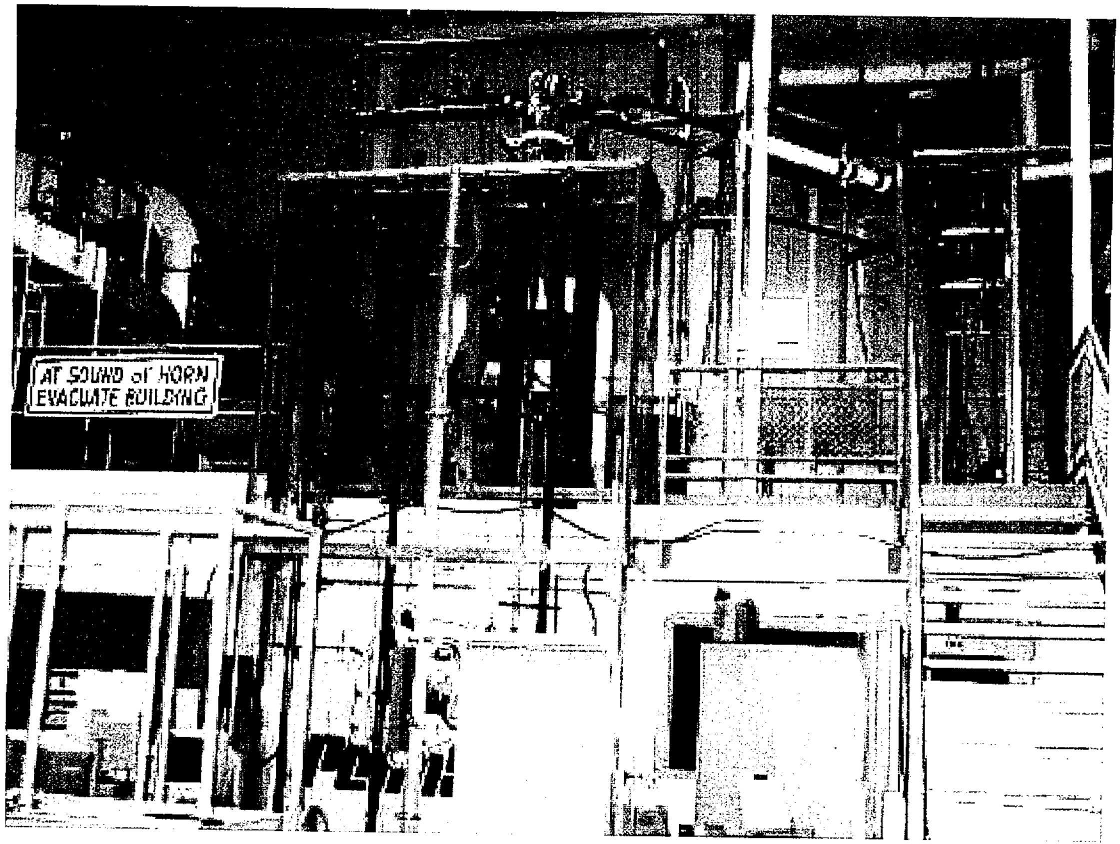



Figure 12 – The riser, chimney sections of the core; crossover leg, and steam separator.

## CONCLUSIONS

The Penn State Low Pressure Integral Test Facility has proved to be a very effective learning tool for Nuclear and Mechanical Engineering students. This facility allows the students to gain "hands-on" learning experiences in design, fabrication, and thermal-hydraulic testing and analysis. It provides the students with an opportunity to observe the complex boiling and two-phase processes that occur in commercial light water reactors and other boiling systems.

Figure 13 – A closer look to the crossover leg and the steam separator.

# ENVIRONMENTAL HEALTH & SAFETY

# X. ENVIRONMENTAL HEALTH AND SAFETY

Environmental Health and Safety (EHS) is an active participant in ensuring the overall safety of the Radiation Science and Engineering Center (RSEC) operations. The RSEC and EHS are committed to the health and safety of the environment, public, students and employees. EHS is responsible for the overall administration of the radiation safety program for The Pennsylvania State University. The University is licensed by the U.S. Nuclear Regulatory Commission (NRC) to receive, acquire, possess, and transfer byproduct material (radioactive material produced by a nuclear reactor), source material (naturally occurring radioactive material, uranium compounds), and special nuclear material (radioactive material that has the potential to undergo nuclear fission) and to operate the Breazeale Nuclear Reactor at the Radiation Science and Engineering Center. The College of Engineering has administration responsibility for the reactor operations license (R-2 license).

The ALARA radiation protection philosophy, keeping the radiation exposure as low as reasonably achievable, is the basis for the RSEC 's radiation protection and safety program. Both groups collaborate to maintain the highest level of health and safety programs necessary for the administration of nuclear programs and compliance with federal and state regulations

Services provided to the RSEC fall into the following categories: "ALARA" programs, customer service, licensing and regulatory requirements, and training.

## ALARA Programs

A major goal of the RSEC and the EHS is to keep radiation exposures as low as reasonably achievable (ALARA). This year EHS performed over 250 radiation surveys at the RSEC. The surveys were conducted to detect possible transferable contamination from radioactive materials work or to survey radiation sources such as activation products, sealed sources, equipment, and reactor operations. The radioactive contamination surveys are performed in laboratories where radioactive materials are used and in the balance of the RSEC's public areas to ensure that no radioactive material has been transferred to these areas. Both the contamination surveys and the radiation surveys are redundant to the surveys performed routinely by the RSEC staff. The redundancy of the contamination and radiation surveys is fundamental to the university's ALARA program. Survey results showed that there were no radioactive contamination surveys or radiation surveys above the established limits.

EHS staff provides representation at Monday and Wednesday morning's RSEC operation meetings. The meetings provide a forum for participants to review the current reactor operations and experiments. This active participation has established an open line of communication between the RSEC and EHS. Input by the radiation protection staff has contributed to the facility's safety and ALARA programs.

**Customer Service**

EHS is responsible for the shipping and transfer of radioactive materials (RAM) to customers other than the RSEC. The U.S. Nuclear Regulatory Commission and U.S. Department of Transportation mandate complex requirements for the packaging, shipping and transfer of radioactive materials. EHS, on a twenty-four hour notice, facilitated eighteen shipments of RAM for RSEC customers. Customer support included packaging and shipping Ar-41, Na-24, and Br-82 for Tru-Tec, and Ar-41 and Br-82 for Synetix. The shipping and transfer of radioactive materials includes the disposal of reactor radioactive waste materials.

**Licensing and Regulatory Requirements**

Requirements for dosimetery are administered by EHS to measure staff, student, and worker radiation exposures. This year the EHS issued a total of 483 dosimeters to RSEC personnel. Administration of the dosimeter program includes issuing dosimeters, processing dosimeters and maintaining all dosimetery records. The RSEC's Director, Dr. Fred Sears, is provided with quarterly dosimeter reports for his review. There have been no doses this year that require investigation. Additionally, EHS provides on request, by signed permission only, dosimetry reports for reactor personnel and students so they can trace their exposure history. EHS provided twenty-one dosimetry reports to other nuclear facilities in order for them to maintain the individual's exposure profile. EHS has administered a thermal neutron dosimeter program to check exposures more accurately for those working around the neutron radiography laboratory. One neutron dosimeter is a permanent fixture in the laboratory, and individuals wear the others as they work in the lab. A total of 135 thermal neutron dosimeters were monitored with no indication of any measurable thermal neutron exposures to personnel. Self-reading dosimeters are issued to transient persons and visitors to the RSEC. The information for the temporary dosimetry is documented in logbooks maintained by the administrative staff at the facility. EHS audits these exposure records to catch errors soon after they occur.

Eric Boeldt, Manager of Radiation Protection, is a member of the Reactor Safeguards Committee. Eric has taken an active role in the Safeguards Committee and has provided input regarding many reactor safety issues brought to the committee's floor this year.

Additional Environmental Health and Safety support this year includes a joint comprehensive safety inspection by EHS and RSEC personnel of the Radiation Science Engineering Center. The team addressed general safety issues, fire safety, chemical safety and chemical waste handling issues. All the deficiencies identified by the team were corrected promptly. EHS staff is responsible for the removal and disposal of the chemical waste generated by at RSEC.

**Training**

Training programs provided by EHS to the RSEC are license and regulatory driven. This year, approximately thirty-five new reactor personnel and students attended the radiation safety orientation. Required retraining for all radiation workers was provided to the RSEC by means of a newsletter distributed to all laboratory supervisors. A special training program was conducted for three RSEC staff members for the shipping of "Limited Quantity of Radioactive Materials". Limited Quantities are small amounts of radioactive material and are not as regulated as larger quantities. The training permits the RSEC staff to expedite small amounts of radioactive materials to be shipped to their main customers. Training is also offered annually to cover chemical and chemical waste handling requirements. All new employees and students attended this mandatory training. Existing staff attended to meet the requirements for mandatory refresher training.

# RADIATION SCIENCE AND ENGINEERING CENTER RESEARCH AND SERVICE UTILIZATION

# XI. RADIATION SCIENCE AND ENGINEERING CENTER RESEARCH AND SERVICE UTILIZATION

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

The reporting of research and service information to the editor of this report is the option of the user, and therefore the projects in Sections A and B are only representative of the activities at the facility. The projects described involved 4 technical reports, presentations, or papers, 15 publications, 5 master's theses, and 3 doctoral 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 under their department and college or under their company or other affiliation. During the past year, 47 faculty and staff members, 28 graduate students and 14 undergraduate students have used the facility for research. This represents a usage by 15 departments or sections in 5 colleges of the University. In addition, 48 individuals from 30 industries, research organizations or other universities used the RSEC facilities.

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

## Agriculture and Biological Engineering Department

### LOW DOSE IRRADIATION OF MEATS PACKAGED IN POLY-LACTIC ACID FOR INACTIVATION OF SALMONELLA PYPHIMURIUM AND E. COLI O157:H7

Participants: Ali Demirci
Virendra M. Puri
Catherine N. Cutter
Kathirivan Krishnamurthy

Service Provided: Gamma Irradiation

In this project, we expect to achieve elimination of pathogenic microorganisms on meats by reduced irradiation doses with polylactic acid (PLA) as packaging material. The specific objectives are: **i)** Investigate the impact of PLA as a packaging material on killing rate of *S* Typhimuriu, and *E. coli* 0157:H7 on meats surfaces during irradiation; **ii.** Evaluate low dose irradiation in combination with PLA for effective elimination of pathogenic microorganisms on meat surfaces; **iii)** Determine the effect of irradiation on mechanical properties of PLA. Experiments with *E. coli* 0157:H7 were performed. Currently, experiments with Salmonella are underway.

Master Thesis:

Krishnamurthy, K., Virendra Puri (Advisor), Ali Demirci (Co-advisor). Low Dose Irradiation of Meats Packaged in Polylactic Acid for Inactiviation of *Salmonella* Typhimurium, and *E. coli* 0157:H7. In Progress

Sponsor: College of Agricultural Sciences – Seed Grant ($10,000)

### RAPID DETECTION OF IRRADIATIVE CHANGES IN FOOD

Participants: Joseph Irudayaraj
Ramazan Kazil

Service Provided: Gamma Irradiation

The gamma irradiation facility at Penn State was used for food irradiation experiments. The objective was to explore the extent of chemical changes in the food due to irradiation. Using the Gamma irradiator at PSU, dose levels of 1, 3 and 10 kGy were applied to different starches such as corn starch, potato starch, waxy starch, high oil containing starch, high protein containing starch, and wheat starch, and starch gels. A total of 54 starch and 50 starch gels were irradiated at the PSU Breazeale reactor center. Starch irradiation experiments were replicated two times in order to check on the uniformity of the gamma irradiation system at PSU. Other products examined are commercial sugars (corn syrup, fructose, beet invert, cane invert) and honey irradiated at various doses (1,5,10, and17kGy). In the future, irradiation experiments will be conducted on amino acids, proteins, and lipids. Finally, irradiation of real food such as meat, chicken and potato will be examined.

Vibrational spectroscopic techniques such as Raman and infrared spectroscopy were used to investigate the extent of irradiated starch samples. Our results on the detection and classification of starch samples have shown that irradiation leads to chemical changes in the starch structure. These changes are characterized using spectral information obtained from both Raman and infrared spectroscopy. Based on the extent of chemical changes in the starch structure, classification was done according to the irradiated dose. Successful differentiation of native (unirradiated) starches from the irradiated one was achieved by processing the spectra using chemometrics.

Doctoral Thesis:

Kazil, R. and J. Irudayaraj (Advisor). Detection and Characterization of Irradiated Food Using Spectroscopic Techniques.

Publications:

Kazil, R., J. Irudayaraj, and K. Seetharaman. Spectroscopic Characterization of Native and Irradiated Starches. Annual Meeting of American Association of Cereal Chemists, October 2001.

Kazil, R., J. Irudayaraj, and K. Seetharaman. Detection of Irradiated Starches Using FT-Raman and FTIR Spectroscopy. Journal of Cereal Chemistry.

## Anthropology Department

### PREHISTORIC METARHYOLITE USE AND MIGRATION IN THE MID-ATLANTIC

Participants: K. Hirth
G. Bondar

Services Provided: Neutron Irradiation, Radiation Counters and Laboratory Space

Four thousand years ago, the Native American cultural continuum of the Mid-Atlantic and Northeastern regions of what is now the United States was apparently interrupted by the introduction of new and unique cultural practices. One diagnostic indicator of this discontinuity in the archaeological record across this region is the appearance of distinctive stone tools, popularly called "broadspears", which were often produced from an uncommon lithic material called metarhyolite. By using neutron activation analysis at Penn State's Breazeale Nuclear Reactor facility, we intend to chemically characterize (or "fingerprint") geologic sources of metarhyolite to match broadspear-related artifacts to their sources of raw material. This unprecedented research, combined with several other quantitative measurements of the artifacts, should help determine whether the distribution of this cultural material from Georgia to New England is due to a prehistoric migration of people, a transfer of cultural traits, or an *in situ* response to environmental perturbations occurring at the end of the third millennium, B.C.

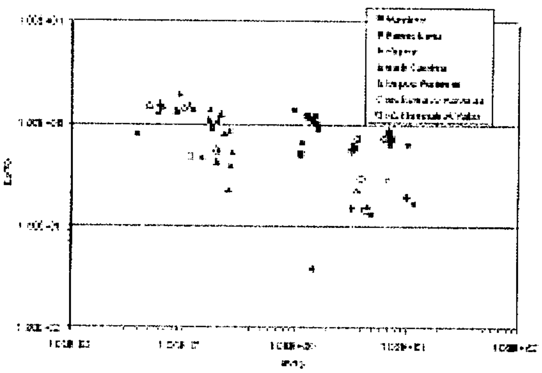


Figure 1: Source analysis of prehistoric metarhyolite artifacts from eastern Virginia.

From the ten runs completed to date, the total of 150 metarhyolitic samples appear to demonstrate that suitable variation exists to permit the compositional discrimination both between and within geologic formations . Preliminary analysis of artifactual material also suggests that metarhyolite from sources in North Carolina was being transported into the Mid-Atlantic region. In addition, the analysis of artifacts from two sites on the Delmarva Peninsula in Virginia suggests that the material was obtained overland from sources in Pennsylvania, rather than from sources across Chesapeake Bay in Maryland or North Carolina, while artifacts from the northern end of the Shennandoah Valley were from the Mt. Rogers source in the Virginia Blue Ridge, as seen in Figure 1. The analysis of geologic sources and artifacts from New England is on-going and planned for completion during the following year.

Doctoral Thesis:

Bondar, G.H., and K.G. Hirth, adviser. Tracing the Transitional. Examining Metarhyolite Use Along the Atlantic Seaboard During the Archaic-Woodland Transition. In progress.

Symposia Organized:

Bondar, G. H. and P. LaPorta. Studying Lithic Economies in the New Millennium. Symposium at the 66th Annual Society for American Archaeology meetings in New Orleans, LA, 2001.

Bondar, G. H. Metarhyolite use during the Transitional Archaic in Eastern North America. Paper presented at the 66th Annual Meeting of The Society for American Archaeology in New Orleans, LAa, 2001.

# Food Science and Technology

## EVALUATION OF GAMMA IRRADIATION FOR DECONTAMINATION OF APPLES

Participants: Steven J. Knabel
Peyman Fatemi
Candace Davison

Service Provided: Gamma Irradiation

Gamma Irradiation up to 1Kgy is currently approved for disinfestation of fruits and vegetables. However, research has shown that higher dosage of gamma irradiation is required to completely eliminate foodborne human pathogens on produce. 1Kgy may reduce the numbers, but, may not be enough to completely destroy these microorganisms. Objective of this work was to evaluate the efficacy of the 1Kgy gamma irradiation against gram-negative pathogens in solution as well as on apple products.
Our results indicate that exposure to 1Kgy gamma irradiation did not result in significant reduction of the foodborne pathogen within various regions of the apple. However, exposure of suspended cells to gamma irradiation led to significant

reduction of the bacterial population. It is important to note that exposure of the apple to radiation did not result in any observable physiological damage.

## INVESTIGATION OF BACKGROUND-FLORA ON COLD SMOKED SALMON FOLLOWING IRRADIATION

Participants: Catherine N. Cutter
Gry Dawn Carl

Service Provided: Gamma Irradiation

*Objective*: To examine the level and nature of background microflora and investigate the effectiveness of a 2 kGy irradiation to reduce microflora of cold smoked salmon.

*Procedure*: Irradiated and non-irradiated salmon were assessed for background microflora immediately after irradiation and again after 7 days of refrigerated storage.

*Method*: At days 0 and 7, samples of irradiated and non-irradiated salmon were homogenized with an aliquot of buffered peptone water, diluted in BPW, and plated directly on microbiological media to allow for growth of mesophilic aerobic bacteria (APC; trypticase soy agar), lactic acid bacteria (LAB; Mann Rogosa Sharpe); *Salmonella* spp. (Xylose lysine decarboxylase); *Brochothrix* spp. (STAA); and *Listeria* spp. (Oxford). Media were incubated at appropriate temperatures and bacterial populations enumerated following incubation.

Results:

*Non-irradiated salmon:*

| Bacterial populations | Day 0 | Day 7 |
|---|---|---|
| APC | $3.76\_10^{5}$ CFU/g | $1.13\_10^{6}$ CFU/g |
| LAB | $1.13\_10^{5}$ CFU/g | $6.00\_10^{5}$ CFU/g |
| *Salmonella* spp. | Not detected | Not detected |
| *Brochothrix* spp. | Not detected | Not detected |
| *Listeria* spp. | Not detected | Not detected |

*Irradiated salmon:*

| Bacterial populations | Day 0 | Day 7 |
|---|---|---|
| APC | $8.18\_10^{2}$ CFU/g | $1.84\_10^{3}$ CFU/g |
| LAB | $8.05\_10^{2}$ CFU/g | $2.05\_10^{3}$ CFU/g |
| *Salmonella* spp. | Not detected | Not detected |
| *Brochothrix* spp. | Not detected | Not detected |
| *Listeria* spp. | Not detected | Not detected |

Note: Irradiation was performed on the following dates:
04/09/01
05/18/01

Master's Thesis:

Carl, Gry Dawn and Catherine N. Cutter (Advisor). This experiment is part of a project for research conducted as partial fulfillment of the requirements for a Master's Degree within the Department of Food Science.

Sponsor: USDA-Foreign Agriculture Service, May 2000 – April 2002 ($30,000)

## Mechanical and Nuclear Engineering Department

### MONITORING AND CONTROL RESEARCH USING A UNIVERSITY RESEARCH REACTOR (PHASE TWO)

Participants: R.M. Edwards
M. Inceñas-Falcón
S. Shyu
W. He
Z. Huang
R. Shaffer

Services Provided: Machine Shop, Electronic Shop, Reactor and Operations Support Staff

*Summary*: The 1999 DOE NEER-funded project on "Monitoring and Control Research Using a University Reactor and SBWR Test-Loop" has completed all of its Phase 2 goals and is ready to proceed to the next phase.

*Phase 2 Discussion:* Two goals were defined for Phase 2, and their accomplishments are briefly discussed.

**The first goal** of Phase 2 (Task 5 in the 3-year project) was to evaluate an on-line uncertainty monitoring system for a robust reactor controller in the research reactor environment, Figure 1. The robust control **Performance Weighting Function** is used in an on-line filter to provide information to help determine the performance of the controller. A real-time nonlinear simulation model of the plant operates in parallel with the plant. The error signals between **Power Demand Signal** and plant output and between **Power Demand Signal** and simulated plant output are inputs to the **Performance Weighting Function** filters. Fuzzy logic is further used to process the outputs of the filters to provide a measure of the controlled system performance. Switching to predefined robust control for different operating ranges can make accommodation of anomalous events, such as excursions into different operating regions.

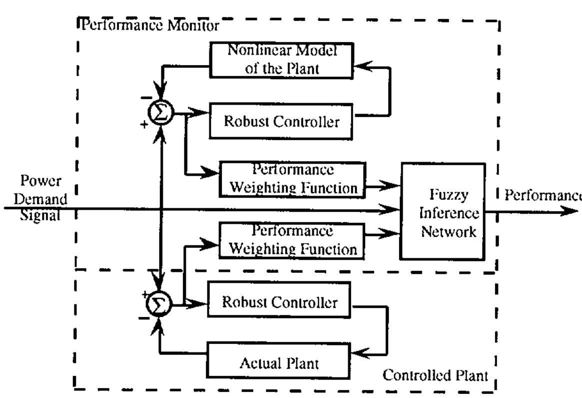



Figure 1: Robust Control Performance Monitor

TRIGA reactor experiments were conducted during Phase 2 to evaluate on-line performance monitoring techniques. New robust control designs were developed to better match experimental conditions available in the TRIGA reactor. A two-dimensional nine-region operating space is obtained by combining three operating ranges on reactor power (nr) and Reactivity Velocity Gain (Rvg). On-line performance monitoring experiments are conducted within the Mathwork's MATLAB/SIMULINK Real-time workshop environment. Figure 2 presents the top-level MATLAB/SIMULINK block diagram. The upper part is employed to control the reactor (real plant). The controller block consists of two robust controllers. The switch block is used to determine which controller is to be used. The lower part provides real-time simulation of the transient in parallel to the reactor experiment, where a nonlinear reactor model is used.

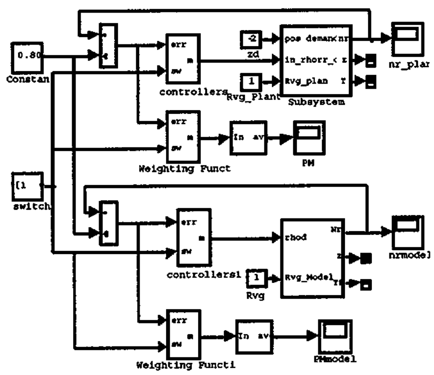


Figure 2: On-line Performance Monitoring Experiment Setup

Some experimental results are presented in Figures 3 and Figure 4. Figure 3 shows the experimental results using the controller designed for the operating range OR21, where the relative power (nr) range is from 0.7 to 1.0 and reactivity velocity gain (Rvg) range is from 0.75 to 1.25. The top two figures present the power response and corresponding output from performance monitor (PM) with Rvg=1.0. The bottom figures give the experimental results obtained with Rvg =0.5, which is out of the design range of the controller for OR21. Figure 4 presents the experimental results using the controller designed for the operating range OR31, which is defined as follows: nr=[0.7 1.0]; Rvg =[1.25 1.75]. According to these experimental results, the PM output shows a larger magnitude and a larger "pulse" width when a controller is working out of its design operating range. These robust-control performance-monitoring characteristics can be incorporated in an on-line decision making process to choose appropriate robust control selection and enforcement.

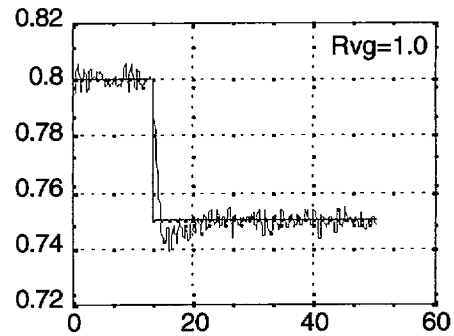



Figure 3: Experimental Results with the Controller for OR21

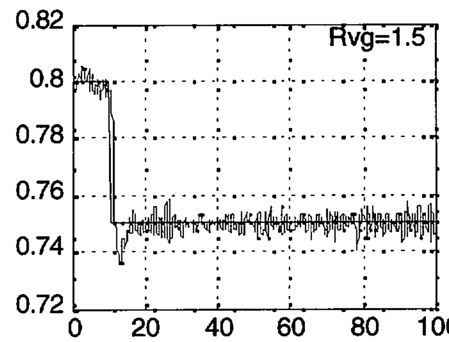



Figure 4: Experimental Results with the Controller for OR31

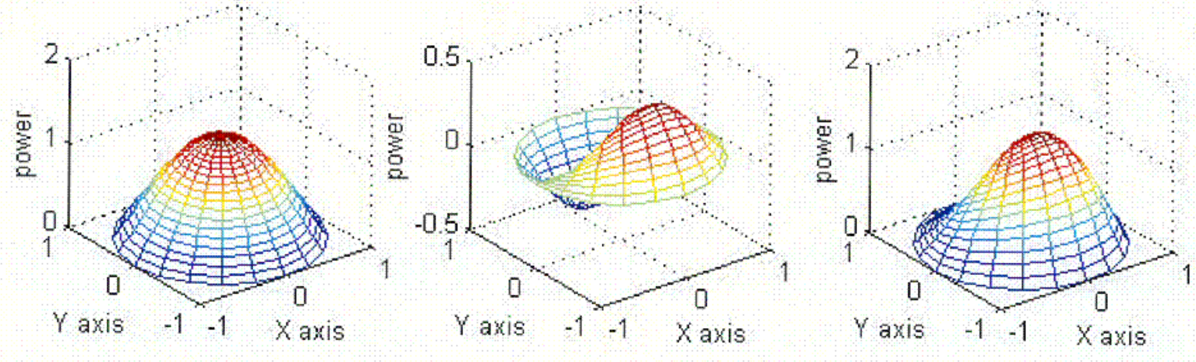
**<u>The second goal of Phase 2</u>** (Task 6 in the 3-year project) was to develop real-time information displays to present the space-time dependent behavior of the out-of-phase reactor BWR stability characteristics.

A fast 3-D reactor power display of modal BWR reactor power distribution was implemented using MATLAB graphics capability as exemplified in Figure 5. Figure 5(a) shows the fundamental mode power distribution over the reactor cross-section.

Figure 5(b) shows the first harmonic power distribution and Figure 5(c) shows the total power distribution over the reactor.

Due to the large amount of computation for BWR boiling channel simulation and real-time data processing and graph generation, one computer is not sufficient to handle these jobs in the hybrid reactor simulation environment. A new three-computer setup has been identified that can efficiently address these requirements and is shown in Figure 6. The host-computer and target-computer work cooperatively under the MATLAB Real-Time Workshop environment. The principal user interaction takes place on the host computer where parameter adjustments are initiated and some elementary information displays are presented. The host-computer and target-computer are connected with network connection; it is therefore possible to separate these two computers over a relatively long distance. The hybrid BWR-simulation application code is generated in the host computer with SIMULINK and is downloaded to the xPC target option of the Real-time Workshop (target computer). The target-computer performs boiling channel thermal-hydraulic simulation and control of the Experimental Changeable Reactivity Device (ECRD) in the TRIGA reactor. The target-computer is connected to the reactor through a DA/AD card. The TRIGA reactor power is measured, and a control signal is sent to the ECRD drive mechanism to simulate the BWR reactivity feedback. Desired hybrid simulation of BWR-reactor behavior is controlled by adjusting parameters in the host-computer. The graph computer retrieves data, both measured reactor power, which serves as the fundamental mode power of BWR, and the simulated first harmonic power from the target computer through serial cable connection. Spatial power distribution is calculated from these data and the reactor physics model in the graph computer and 3-D display of BWR reactor power of the two modes together with the total power is displayed there.

At the end of Phase 2, the graph computer and the host computer functions were implemented in the same 550 MHz computer, thus the refresh interval on the 3-D graph generation was undesirably long. A new 1.5 GHz computer will be added so that the graph functions can be executed at a desirable frequency of 10 Hz.




(a) Fundamental mode (b) First harmonic (c) Total power

**Figure 5**: Example of 3-D real-time information display for BWR out-of-phase (OOP) oscillation (normalized by the initial power)



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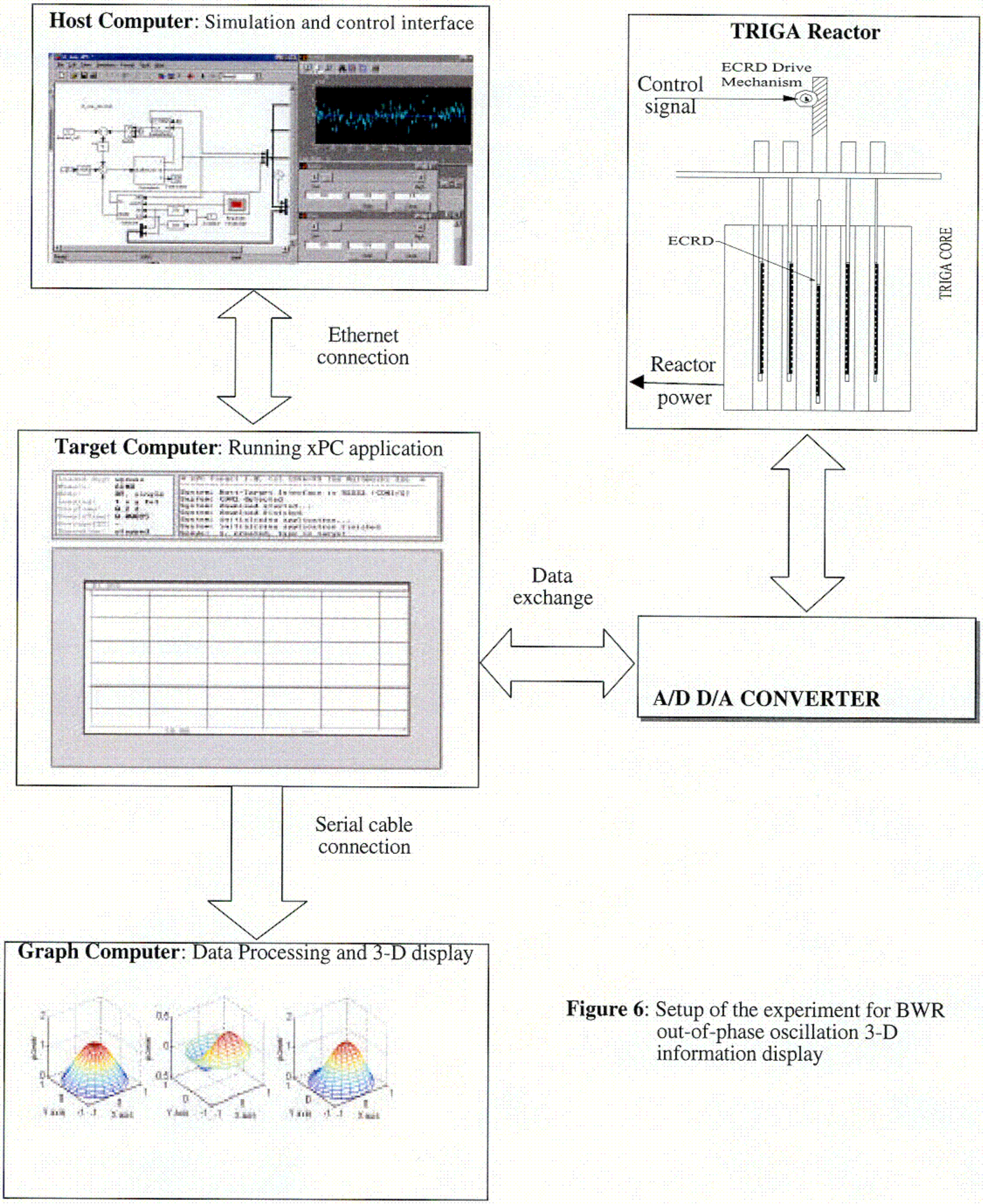


**Figure 6**: Setup of the experiment for BWR out-of-phase oscillation 3-D information display



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## CONCLUSION:

The 1999 DOE NEER-funded project on "Monitoring and Control Research Using a University Reactor and SBWR Test-Loop" has completed all of its Phase 1 and 2 goals and is ready to proceed to the next phase. Phase 3 is scheduled to run from January 1, 2001 to June 30, 2001. The Phase 3 goals are 1) develop and validate a simulation model of the testloop, which is suitable for simulation of a parallel channel for use as feedback to the first harmonic of the modal kinetics model. The HLS will then be expanded to include hybrid simulation of out-of-phase stability characteristics and 2) will implement and evaluate in-phase and out-of-phase BWR stability monitoring techniques that have been developed and demonstrated in strictly simulation environments in recent years.

Publications:

The following seven publications and presentations were made during Phase 1:


1. *Ceceñas-Falcón, M., and R.M. Edwards. July 2000. Stability Monitoring Tests Using a Nuclear-Coupled Boiling Channel. *Nuclear Technology.* 131:1-11.
2. Ceceñas-Falcón, M., and R.M. Edwards. November 2000. Out-of-Phase BWR Stability Monitoring. *Proceedings of The Third American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies, NPIC&HMIT'2000.* 9 pages on CD ROM. Washington, DC
3. Shyu, S., and R.M. Edwards. November 2000. Optimized-Feedforward and Robust-Feedback Used in Integrated Automatic Reactor Control. *Proceedings of The Third American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies, NPIC&HMIT'2000.* 8 pages on CD ROM. Washington, DC.
5. He, W., Z. Huang, and R.M. Edwards. November 2000. Experimental Validation of Optimized-Feedforward Control for Nuclear Reactors. *Proceedings of The Third American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies, NPIC&HMIT'2000.* 8 pages on CD ROM. Washington, DC.
6. Huang, Z., and R.M. Edwards. November 2000. Hybrid Reactor Simulation of BWR Using a First Principle Boiling Channel Model. *Proceedings of The Third American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies, NPIC&HMIT'2000.* 8 pages on CD ROM. Washington, DC.
7. Shaffer, R., W. He, and R.M. Edwards. November 2000. Experimental Validation of Robust Control for Nuclear Reactors. *Proceedings of The Third American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies, NPIC&HMIT'2000.* 9 pages on CD ROM. Washington, DC.
8. Edwards, R.M., Z. Huang, and W. He. November 2000. Integration of a Thermal-Hydraulic Test-loop and University Research Reactor for Advanced Monitoring and Control Research. *Proceedings of The Third American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies, NPIC&HMIT'2000.* 8 pages on CD ROM. Washington, DC.

The following two publications were accepted or submitted during Phase 2:

9. *Eceñas-Falcón, M., and R.M. Edwards. Application of a Reduced Order Model to BWR Corewide Stability Analysis. To appear in *Annals of Nuclear Energy.*

10. Shaffer, R., and R.M. Edwards. Design and Validation of Robust Control for Nuclear Reactors. *IEEE Transactions on Control Systems Technology.* submitted October 2000.

Sponsor: Department of Energy

**NE 451, UNDERGRADUATE LABORATORY OF REACTOR EXPERIMENTS**

Participants: R. M. Edwards
J. S. Brenizer
M. E. Bryan
T. L. Flinchbaugh
B. J. Heidrich
C. F. Sears

Services Provided: Laboratory Space, Machine Shop, Electronics Shop, SUN SPARC Server Computer System, Neutron Irradiation Using Subcritical Pile, Reactor Instrumentation and Support Staff

The Nuclear Engineering 451 course is the second of two 3-credit laboratory courses required of all Penn State Nuclear Engineering undergraduates and is typically taken during the Fall of the senior year. Each weekly laboratory exercise usually consists of two lectures and one laboratory session. By the beginning of the senior year, the students have already covered the LaMarsh Introduction to Nuclear Engineering text including reactor point kinetics. The 451 course emphasizes experiments using the instrumentation that was covered in NucE 450 and is divided into two (more or less) equal "tracks".

These tracks can be coarsely described as TRIGA and non-TRIGA experiments and each is the major responsibility of a different professor. The non-TRIGA track includes three graphite pile, two reactor operation experiments, and a xenon poisoning simulation. In 2000, the TRIGA track included:

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

This sequence was first introduced in 1991, when the reactor control experiment replaced a reactor gamma field measurement experiment and the digital simulation exercise was modified to point kinetics from its previous focus on Xenon dynamics. The laboratory utilizes Macintosh computers with GW Electronics MacAdios Jr. data acquisition hardware and Superscope II software. The Superscope II software was a major software upgrade for 1993, and with its new point-by-point seamless mode enabled effective reactivity calculations and control experiments. The Mathworks SIMULINK simulation software was used for the digital simulation exercise for the first time in 1992. Reactor control is offered as a graduate course in our department but until 1991, our undergraduates did not receive a complete introduction to feedback control. In the Fall of 1994, a new UNIX network compatible control system was utilized for the reactor control experiment. The new system was also acquired to enhance the NSF/EPRI sponsored research and is described in more detail in subsequent sections. The UNIX Network compatible controller programming is performed using the Mathworks SIMULINK block programming language in a SUN SPARC workstation. An automatic C code generation process produces and downloads the necessary real-time program for execution in a microprocessor-based controller with an ETHERNET network interface to the host workstation.

The 1994 version of the control experiment thus unified all of the MATLAB/ SIMULINK instruction earlier in the course into a demonstration of state-of-the-art CASE-based control system design and implementation. In 1998, the UNIX network compatible control system was made obsolete by the availability of a Windows NT implementation of the MathWorks SIMULINK environment. The Windows NT platform became available as a result of the DOE NEER grant project on "Monitoring and Control Research Using a University Research Reactor" described elsewhere in this report.

## PENN STATE NEUTRON RADIOGRAPHY FACILITY

Participants: Shane Hanna
Marcia Chesleigh
Jack Brenizer

Services Provided: Neutron Radiography, Machine Shop

The Pennsylvania State University's Breazeale Nuclear Reactor, now a part of the Radiation Science and Engineer Center, has a long history of neutron imaging. Construction began in 1954 and was licensed in July 1955 as license R-2. In 1970 the reactor facility was named after its first Director, Dr. William M. Breazeale. Important to neutron radiography was the incorporation of beam ports in the initial construction. However, these beam ports were not seriously used for neutron imaging until the early 1970's. The power of the reactor was increased from 100 kW to 200 kW in 1960 when the highly enriched uranium plate type fuel core was used. In 1965 the core was converted to a General Atomics TRIGA core rated 1000 kW. This conversion and power upgrade was instrumental to neutron radiography. Additionally, the ability to pulse the core up to 2000 MW gave the possibility of pulsed neutron radiography.

In 1970, modifications to the facility impacting neutron radiography included modification of the rails on the pool walls to permit better core positioning relative to the beam ports and addition of a $D_2O$ thermal column. The gains in thermal flux at the beam ports opened the possibility for neutron imaging research. Drs. Jacobs and Kenney began a series of research projects utilizing the then new field of dynamic neutron imaging. The next major step in neutron radiography occurred in the mid-1980's, starting with a research project on automotive gas springs with Dr. Samuel Levine and Daniel Hughes. This project lead to the introduction of modern neutron radioscopy techniques at the facility. Several major investigations using neutron radioscopy followed. In 1994, major modifications were made to the beam laboratory and the reactor superstructure to accommodate a two-phase flow experiment. Dr. Sathianathan worked with the staff to convert the beam from a radial to a tangential beam, dramatically reducing the gamma photon flux in the neutron beam. The construction of a new $D_2O$ thermal column, the addition of translational and rotational motion to the core superstructure, and the purchase of imaging equipment improved the neutron imaging capabilities. In 1998, the shielding for the beam was improved, and work began to improve the collimator design.

At the beginning of the new century, improvements continue to be made. Current efforts are focused on improving the beam quality, shielding and imaging capabilities. Neutron radiography continues to play a major role in the utilization of the reactor.

Presentation:

Hanna, S., M. Chesleigh, and J. Brenizer. June 2001. 4th International Topical Meeting on Neutron Radiography, Poster Session, State College, PA

## NEUTRON RADIOGRAPHY EXPERIMENTS FOR VERIFICATION OF SOLUBLE BORON MIXING AND TRANSPORT MODELING UNDER NATURAL CIRCULATION CONDITIONS

Participants: G. M. Morlang
J. Brenizer, Jr.

Services Provided: Neutron Radiography, Machine Shop

The use of neutron radiography for visualization of fluid flow through flow visualization modules has been very successful. Current experiments at the Penn State Breazeale Reactor serve to verify the mixing and transport of soluble boron under natural flow conditions as would be experienced in a pressurized water reactor.

Different flow geometries have been modeled including holes, slots, and baffles. Flow modules are constructed of aluminum box material 1/4 inch by 4 inches in varying lengths. An experimental flow system was built which pumps fluid to a head tank and natural circulation flow occurs from the head tank through the flow visualization module to be radiographed. The entire flow system is mounted on a portable assembly to allow placement of the flow visualization module in front of the neutron beam port. The entire sequence is recorded on real-time video. Still photographs are made frame-by-frame from the video tape. Computers are used to digitally enhance the video and still photographs. The data obtained from the enhancement will be used for verification of simple geometry predictions using the TRAC and RELAP thermal-hydraulic codes.

A detailed model of a reactor vessel inlet plenum, downcomer region, flow distribution area and core inlet is being constructed to model the AP600 plenum. Successive radiography experiments of each section of the model under identical conditions will provide a complete vessel/core model for comparison with the thermal-hydraulic codes.

Publication:

Morlang, G.M. June 2001. 4th International Topical Meeting on Neutron Radiography, State College, PA

## ANALYSIS AND TESTING OF THE DIVERGENCE AND ALIGNMENT INDICATOR USING THE PENN STATE NEUTRON RADOGRAPHY BEAM

Participants: M. Chesleigh
J. Brenizer, Jr.

Services Provided: Neutron Radiography, Machine Shop

The divergence and alignment indicator (DAI) was developed to test the alignment of objects in a neutron beam, the divergence angle and centerline position of the beam. The construction of such a device was intentionally kept simple to allow ease of implementation. The DAI consists of an aluminum plate and rods, and cadmium wire for contract. Two cadmium wire pieces, one on the plate surface and other in the end of the post, allow for the determination of alignment. If only one wire is visible, then the plate is aligned. The degree and direction of misalignment can be found by the replacement of the wires with respect to each other. A "+" is made by placing wire pieces at the intersection of circular and radial grooves in the plate. The difference between the distance on the film and on the plate from the center wire to a cadmium "+" can be used to determine the divergence angle.

The DAI was tested in the Penn State University's neutron radiography beam. By developing the three basic cases (aligned, aligned only in one direction, and completely misaligned), the equations for the device[1] were tested and determined to be correct and accurate for each case. Furthermore, the error of the device was found to be ±0.065° (approximately 10% at a radius of approximately 6.0 cm) with posts approximately 10 cm in length, and a measuring error of ±0.5 mm.

The most prominent weakness of the device is the precision necessary in the construction. For example, the top of the plate must be precisely flat. Otherwise, the minor difference in height will lead to large discrepancies in the data, making any analysis worthless. Furthermore, the two wires indicating alignment must be precisely on top of one another, and the 5 posts must be precisely the same length and perpendicular to the plate face.

Presentation:

Chesleigh, M. and J. Brenizer. June 2001. 4th International Topical Meeting on Neutron Radiography, Poster Session, State College, PA

**EVIDENCE FOR IRRADIATION-INDUCED METALLIC PRECIPITATES IN NEUTRON IRRADIATED MODEL ALLOYS AND PRESSURE VESSEL WELD STEEL, USING DOPPLER-BROADENING POSITRON SPECTROSCOPY**

Participants: S. E. Cumblidge
A. T. Motta
G. L. Catchen
G. Brauer

Services Provided: Neutron Irradiation, Radiation Counters, Laboratory Space, Angular Correlations Lab

We have been using positron Doppler-broadening spectroscopy to examine a series of neutron-irradiated model alloys and 73W-weld steel. The composition of the model alloys was systematically varied in the amounts of copper, nickel and phosphorus. The 73W-weld steel contains 0.31% copper and 0.60% nickel. The samples were examined in the non-irradiated and neutron-irradiated states, as well as after successive isochronal anneals at temperatures ranging from 200 to 600 °C. The model alloys were irradiated to $1x10^{19}$ n/cm$^2$ (E>0.5 MeV) and the 73W-weld steel was irradiated to $1.8x10^{19}$ n/cm$^2$ (E>1 MeV). By comparing the Doppler-broadening spectroscopy W-parameters measured in pure metals with those measured in the materials in this study, we were able to draw inferences as to the nature of the irradiation induced defects that cause hardening and embrittlement. The results indicate that the damage is a combination of irradiation induced metallic precipitates (with varying degrees of Cu) and defect clusters. In irradiated samples with high Cu concentration, the W-parameter showed evidence for annihilations occurring mostly at Cu-rich precipitates. Samples with high Ni and medium Cu showed evidence for irradiation induced metallic precipitation with a different chemistry, while samples without high Ni or high Cu showed evidence only of open volume defect clusters. These defect clusters disappeared upon annealing at 400-500 °C , whereas the metallic precipitates generally did not decrease until 600 °C. The pressure vessel weld steel sample showed a behavior that could be well understood using the model valid for the model alloys above, i.e. a combination of defect clusters and irradiation induced metallic precipitates causing embrittlement.

Doctoral Thesis:

Cumblidge, S.J., G. L. Catchen (co-advisor), and A. T. Motta (co-advisor). Characterizing Radiation Effects in Reactor Pressure-Vessel Steels and Model Alloys Using Positron Spectroscopies.

## PHYSICS OF FLOWING POLYMERS: DRAG REDUCATION IN TURBULENT FLOWS

Participants: G. L. Catchen
Adele' Poyner
John McGrory
Lance Collins
James Brasseur
Janna Maranas
Kristin Fichthorn
Ralph Colby

Services Provided: Neutron Irradiation, Isotope Production, Laboratory Space, Angular Correlations Lab

Low concentrations of linear polymers can reduce frictional losses in various types of fluid transport such as flow in oil pipelines and flow around ships and submersibles. Despite over 40 years of research, investigators have not been able to observe directly the polymer-solvent interactions, which are responsible for the macroscopic drag reduction. To observe these polymer-solvent interactions, using a unique, new approach, we are applying perturbed-angular-correlation (PAC) spectroscopy. This technique is based on tagging a very small fraction of polymers with radioactive probe ions, $^{111}$In or $^{181}$Hf, which act as "rotational tracers" and which are used to measure nano-scale relaxation times associated with polymer motion including rotation.

During this first phase, we are developing techniques to bind the PAC probe ions to several different polymers. We are performing PAC experiments using systems in which no fluid flow takes place. We are investigating the dependence of the nano-scale relaxation time on temperature and on the solvent composition. These experiments are providing the prerequisite knowledge that we will need to design and to interpret the flow experiments.

This project is part of a much larger program, in which we couple the unique sensitivity of the experimental PAC technique with several sophisticated computational techniques. The overall objectives of this large program are (1) to understand the fundamental physics of flowing polymers that give rise to drag reduction and (2) ultimately, by developing accurate models, to optimize drag-reducing agents.

Sponsor: Petroleum Research Fund of the American Chemical Society (2 years)

## ELECTRIC-FIELD GRADIENTS AT THE Zr-SITES IN $Zr_3Fe$: MEASURED USING PERTURBED-ANGULAR-CORRELATION SPECTROSCOPY AND CALCULATED USING BAND THEORY

Participants: A. T. Motta
S. E. Cumblidge
G. L. Catchen
S. B. Legoas
E. L. Amaral

Services Provided: Neutron Irradiation, Laboratory Space, Angular Correlation Laboratory

At the two Zr-sites in the intermetallic compound $Zr_3Fe$, we have measured the electric-field-gradient (EFG) parameters $V_{zz}$ and $\eta$ and their temperature dependences using perturbed-angular-correlation (PAC) spectroscopy and the probe $^{181}Hf \rightarrow {}^{181}Ta$, which substitutes into the Zr-sites in $Zr_3Fe$. At temperatures below the peritectic transformation at $\approx 1158$ K, at each Zr-site, we observed well-defined EFGs characterized by sharp spectral lines. A low-frequency, nearly axially-symmetric nuclear electric-quadrupole interaction characterizes the Zr-site, which represents approximately two-thirds of the probes. A high-frequency, very asymmetric nuclear electric-quadrupole interaction characterizes the Zr-site, which represents approximately one-third of the probes. The temperature dependences of $V_{zz}$ and $\eta$ reflect highly anisotropic nature of the vibrational modes that characterize the $Zr_3Fe$ crystal. Near and above the peritectic transformation, the results show qualitatively the effects of decomposition of $Zr_3Fe$ into Zr and $Zr_2Fe$ and subsequent melting. We have compared the values of $V_{zz}$ and $\eta$ measured at laboratory temperature to those calculated using the Real Space Linear Muffin Tin Atomic Sphere Approximation (RS-LMTO-ASA) band-theory method. Overall the magnitudes of $V_{zz}$ and $\eta$ calculated using the RS-LMTO-ASA method agree reasonably well with the experimental values. However, two discrepancies arise for which we have no singular explanation.

Publications:

Motta, A. T., S. E. Cumblidge, G. L. Catchen, S. B. Legoas, and L. Amaral. Electric-Field Gradients at the Zr-Sites in $Zr_3Fe$: Measured Using Perturbed-Angular-Correlation Spectroscopy and Calculated Using Band Theory. Accepted for publication in Physical Review B, Sept. 2001.

## COMPTON SCATTER GAUGE

Participants: E. H. Klevans
E. S. Kenney
W. He
S. Li
C. Grapes
B. L. Wilks
M. E. Bryan
B. J. Heidrich
R. L. Eaken
M. P. Grieb

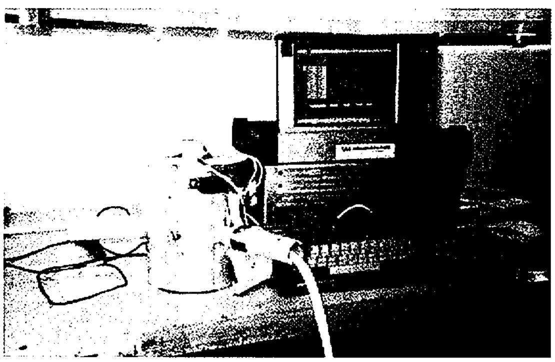
Services Provided: Hot Cell Lab, Laboratory Space, Machine Shop and Electronics Shop

Measurement of pipe walls for erosion is accomplished without removing insulation by use of a gamma ray backscatter thickness gauge. The device can measure wall thickness in empty pipes or in fluid-filled pipes up to 0.5 inches thick. The isotope Hg-203 provides the gamma source, which is produced by irradiating approximately one gram of HgO at the Missouri University Research Reactor.

Assembly of the Compton Scatter Gauge

These sources are removed in the hot cell at Penn State University from the irradiation assembly and transferred to the shield used in the device. A Monte Carlo analysis by W. He showed that the amount of HgO could be reduced by 2/3 without reducing the gamma output. A new detector unit with a diameter of 4.5" NaI detector (as opposed to the previous units with a 3.25" diameter crystal) was purchased by NMC and sent to Penn State. It was determined that the crystal was very sensitive to orientation change, indicating a crack was present. However, it performed reliably if a vertical orientation was maintained. Several broad focus collimators were made to study focusing properties for 2", 3" and 4" CaSi insulation.

Detailed studies were performed with a range of broad focus collimators on both units and it was demonstrated that, for air-filled systems, there is little count rate change over +/- 0.25" change in insulation thickness. For water-filled systems a different technique is required because



Compton Scatter Gauge with computer that converts count rate to thickness

narrow focus collimators must be used. The most satisfactory method uses a combination of a no-collimator response matrix for different plate and insulation thickness combined with a focus curve matrix for different plate and insulation thickness. Tests in the laboratory showed the method was quite accurate. However it needs to be computer automated.
Studies were conducted to determine the measurement errors that would result from wet insulation with several different densities, and also errors that would result from ice layers below insulation or above insulation. In this case sheets of 0.125" polyethylene were used to simulate ice. The magnitude of the errors and ability to spot them was determined and discussed in a report to Exxon.

Weidong He, Graduate Student, demonstrates pipe wall thickness measurement using Compton Scatter Gauge

Master's Theses:

He, W., E.H. Klevans and E.S. Kenney (co-advisers). Measurement of Wall Thickness with Varying Radiation Background. December 2000

Li, S., E.H. Klevans and E.S. Kenney (co-advisers). Monte Carlo Collimator Modeling and Testing of the Compton Backscatter Gauge. In progress.

Publication:

Klevans, E.H., E.S. Kenney, S Li, and B. Wilks. Phase 2B Final Report to MobilExxon.

Sponsors: Nuclear Measurements Corporation - $15,000
MobilExxon Research Corporation - $34,000

## CHARACTERIZATION AND IMPROVEMENT TO THE NEUTRON RADIOGRAPHY FACILITY

Participants: J. S. Brenizer
C. F. Sears
M. E. Bryan
T. L. Flinchbaugh
P. R. Rankin
S. Hanna
B. J. Heidrich
D. E. Hughes
R.L. Eaken
J.A. Armstrong

Services Provided: Neutron Radiography, Machine Shop

As a result of a need for increased neutron beam intensity for a sponsored two-phase flow research project, the $D_2O$ thermal column and neutron radiography beam port were replaced with a new integral $D_2O$ tank and beam port system in 1997. The new system was integrated with modifications to the reactor bridge and superstructure work completed in 1994. The bridge modifications permit movement of the reactor core in the lateral (east-west) directions and in the rotational direction. These added degrees of motion, coupled with the new $D_2O$ thermal column, allowed the neutron radiography beam to be oriented tangential to the core thus reducing the gamma component of the beam. Currently, efforts are underway to improve collimator design to increase the L/D ratio without significantly degrading the n/$\gamma$ ratio. The higher flux levels produced with the new beam required complete replacement of the shielding to allow personal access in the neutron beam laboratory during neutron imaging and measurement experiments. The shield design permits flexibility with respect to the shielding configuration to accommodate present and future experiments. Characterization of the neutron beam and collimator design is ongoing.

Paper:

Brenizer, J.S, D.E. Hughes, M.E. Bryan, R. Gould, T.L. Flinchbaugh, and C.F. Sears. Characterization of the Penn State Neutron Radiography Facility. Presented at the Neutron Imaging Methods to Detect Defects in Materials Meeting, Nuclear Energy in Central Europe 1999, World Conference on Neutron Radiography, Osaka, Japan. May 17-21, 1999.

## NUCE 450, RADIATION DETECTION AND MEASUREMENT

Participants: J. S. Brenizer

Services Provided: Neutron Irradiation, Reactor Instrumentation, and Laboratory Space

NucE 450 introduces the student to many of the types of radiation measurement systems and associated electronics used in the nuclear industry as well as many of the mathematical techniques used to process and interpret the meaning of measured data. The radiation instruments studied in this course include GM detectors, gas flow proportional counters, NaI (Tl) detectors, BF3 counters, ion chambers, wide range GM detectors, and surface barrier detectors. The data collection and analysis techniques studied include radiation counting statistics, gamma ray and charged particle spectroscopy, and the interfacing of computers with nuclear instrumentation.

## DEVELOPMENT AND VALIDATION OF ADVANCED FUEL MANAGEMENT SYSTEM FOR PSBR TRIGA

Participants: Nateekool Kriangchaiporn
Kostadin Ivanov
Fred Sears
Mike Morlang
Brenden Heidrich

Service Provided: Reactor

The earlier TRIGA core management model was developed and performed by using PSU-LEOPARD, EXTERMINATOR2, and MCRAC codes. These codes introduce prediction inaccuracies due to applying several assumptions and modeling limitations. To more accurately represent the actual TRIGA core behavior an advanced fuel management code system for PSBR has been developed based on the HELIOS lattice-physics code and the multi-dimensional nodal diffusion code ADMARC-H. The obtained qualification results indicate that the new systems predicts the core parameters much better as compared to the measured data, and it is computationally efficient and user friendly. The application of this system will result in an enhanced core analysis and development of new TRIGA fuel management program designed to improve safety and increase efficiency of reactor operation.

Master's Thesis:

Kriangchaiporn, N., K.K. Ivanov, C.F. Sears, G.M. Morlang, and B.J. Heidrich. Advanced Fuel Management Code System for PSBR, TANSAO, vol. 85, p. 415. November 2001.

Sponsor: Radiation Science and Engineering Center

# Northeast Technology Corp.

## QUALIFICATION OF METAMIC® FOR WET AND DRY NUCLEAR FUEL STORAGE APPLICATIONS

Participants: D. Vonada
K. Lindquist

Services Provided: Neutron Irradiation, Neutron Radiography, Laboratory Space

This project involves the qualification of a 6061 aluminum alloy/boron carbide composite material for spent nuclear fuel storage applications. The material is being qualified for both wet (in pool) and dry (cask storage) applications and is used to maintain the spent fuel in a subcritical condition. The qualification testing includes accelerated corrosion tests, elevated temperature tests and accelerated radiation testing. The testing has demonstrated that this material is an ideal candidate for criticality control in wet and dry nuclear fuel storage applications.

## TESTING OF NEUTRON ABSORBER SURVEILLANCE COUPONS

Participants: D. Vonada
K. Lindquist

Services Provided: Neutron Irradiation, Laboratory Space

When spent nuclear fuel storage racks are installed in spent fuel pools a series of surveillance coupons are also installed. Periodically coupons are removed and tested to assure integrity of the neutron absorber. Tests conducted at RSEC include complete physical characterization, neutron attenuation and metallography where appropriate. The materials tested include BORAL, Boraflex, borated graphite and borated stainless steel.

## Veterinary Science

**CONTROL OF HEMATOPOIESIS BY THE MURINE *POLYCYTHEMIA* GENE**

Participants: Robert Paulson
Li Hao

Service Provided: Gamma Irradiation

Mutation of the murine *Polycythemia (Pcm)* gene causes the overproduction of mature blood cells. We wished to test whether the *Pcm* mutation causes an intrinsic defect in the responses of hematopoietic progenitors to cytokines or whether the phenotype results from an altered microenvironment in the bone marrow. If the defect is intrinsic to the progenitor cells, the mutant phenotype can be transferred to a normal mouse by transplanting mutant bone marrow into a normal mouse. Prior to transplantation the recipient normal mice must first be irradiated to ablate the host bone marrow. After several pilot projects, we determined that the irradiator at the Breazeale facility was not suitable for our project. We are now seeking alternatives.

Sponsor: American Cancer Society Research Scholar Grant #RSG-01-083-01-LIB

## SECTION B. OTHER UNIVERSITIES, ORGANIZATIONS AND COMPANIES UTILIZING THE FACILITIES OF THE PENN STATE RADIATION SCIENCE AND ENGINEERING CENTER

| University or Industry | Type of Use |
|---|---|
| Bettis Labs, Westinghouse | Neutron Radiography |
| Bio-Pore Inc. | Gamma Irradiation |
| Commonwealth Edison Company | Compton Scatter Gauge Development |
| Durect Corporation | Neutron Radiography |
| Eagle-Picher | Neutron Radiography<br>Neutron Radioscopy<br>Neutron Transmission |
| Exelon | Neutron Transmission |
| Exxon Research Corporation | Compton Scatter Gauge Development |
| Fairchild Corporation (formerly Intersil) | Semiconductor Irradiation |
| Institut für Ionestrahlphysik and Materialforschung, Dresden, German | Perturbed Angular Correlation |
| Institut für Sicherheitsforschung, Dresden, Germany | Perturbed Angular Correlation |
| Instituto de Fisica, Rio Grande do Sul, Brasil | Perturbed Angular Correlation |
| Instituto de Fisica, Sao Paulo, Brasil | Perturbed Angular Correlation |
| Lockheed Martin | Semiconductor Irradiation |
| NETCO (Northeast Technology Corporation) | Neutron Radioscopy<br>Neutron Transmission |
| Oglevee Ltd. | Gamma Irradiation |
| PPL | Gamma Irradiation |
| Precious Minerals Mining & Refining Corp. | Neutron Activation Analysis |
| Pro-Clinical | Neutron Radiography |
| Raytheon Company, Sudbury, MA | Irradiation of Electronic Devices |
| Raytheon Systems Company, El Sequndo, CA | Irradiation of Electronic Devices |
| SAIC | Irradiation of Electronic Devices |
| St. Louis Metallizing | Neutron Transmission |
| Suntronics, Inc. | Semiconductor Irradiation |
| SVTI-ASIT, Switzerland | Neutron Transmission |
| Synetix | Isotope Production |
| Transnucleaire, France | Neutron Radiography<br>Neutron Radioscopy<br>Neutron Transmission |
| Tru-Tec | Isotope Production |
| TRW | Semiconductor Irradiation |
| TTH, Inc. | Neutron Radiography |
| University of Maryland | Perturbed Angular Correlation |

# APPENDICIES

# APPENDIX A

Personnel Utilizing the Facilities of the Penn State RSEC.
Faculty (F), Staff (S), Graduate Student (G), Undergraduate (U),
Visiting Professor (VP), Visiting Scholar (VS), Faculty Emeritus (FE), Post-Doctoral (PD)

## COLLEGE OF AGRICULTURE

| Agriculture & Biological Engineering: | |
|---|---|
| Demirci, Ali | F |
| Irudayaraj, Joseph | F |
| Puri, Virendra M. | F |
| Kazil, Ramazan | G |
| Krishnamarthy, Kathirivan | G |
| **Food Science & Technology:** | |
| Cutter, Catherine N. | F |
| Knabel, Steven J. | F |
| Fatemi, Peyman | G |
| Carl, Gry Dawn | G |
| **Plant Pathology:** | |
| Juba, Jean | S |
| **Veterinary Science:** | |
| Paulson, Robert | F |
| Wojchowski, Don | F |
| Hao, Li | G |
| Pandev, Ajay | G |
| Zhao, Shiang | G |
| Zhao, Shuging | G |

## COLLEGE OF ENGINEERING

| Chemical Engineering: | |
|---|---|
| Collins, Lance | F |
| Maranus, Janna | F |
| Fichthorn, Kristin | F |
| **Electrical Engineering** | |
| Jeong, Dae Yong | G |
| Lu, Yu | G |
| Zhang, Qiming | F |
| **Engineering Science & Mechanics:** | |
| Mishener, Tetsuya | G |
| Lenahan, P | F |
| **Material Science & Engineering:** | |
| Colby, Ralph | F |
| **Mechanical & Nuclear Engineering:** | |
| Adamonis, Jaclyn | U |
| Brasseur, James | F |
| Brenizer, Jack | F |
| Bryan, Mac | S |
| Buschman, Francis | U |
| Butler, Jennifer | U |
| Catchen, Gary | F |
| Cecenas-Falcon, M | G |
| Chesleigh, Marcia | U |

| Mechanical & Nuclear Engineering (cont.): | |
|---|---|
| Cimbala, John M. | F |
| Cumblidge, Stephen | G |
| Daubenspeck, Thierry | S |
| Davison, Candace | S |
| Decker, Chandra | U |
| Eaken, Ronald | S |
| Edwards, Robert | F |
| Ehrenberger, Steve | U |
| Flinchbaugh, Terry | S |
| Grieb, Mark | S |
| Hahn, Diana | U |
| Hanna, Shane | U |
| He, Weidong | G |
| Heidrich, Brenden | G |
| Hochreiter, Larry | F |
| Huang, Zhengzyu | G |
| Kenney, Edward | FE |
| Klevans, Edward | FE |
| Kohlepp, Kaydee | U |
| Kriangchaiporn, Nateekool | G |
| Lebiedzik, Jana | S |
| Levine, Samuel | FE |
| Li, S. | G |
| Link, Travis | U |
| McGrory, John | U |
| Morlang, Michael | S |
| Motta, Arthur | F |
| Nixon, Wayne | U |
| Portanova, Alison | S |
| Poyner, Adelé | U |
| Rankin, Paul | S |
| Rasera, Rob | VP |
| Rudy, Kenneth | S |
| Schaeffer, Roman | G |
| Sears, C. Frederick | F |
| Shyu, S | G |
| Vincenti, John | S |
| Werkheiser, Dave | S/U |
| Whisker, Vaughn | G |
| Wilks, Ben | G |

## COLLEGE OF SCIENCE

| Chemistry: | |
|---|---|
| Allcock, Harry | F |
| Ambler, Cathy | G |
| Chalkova, Elena | G |
| Hofmann, M | G |
| **Physics:** | |
| Florend, Richard | F |

| COLLEGE OF LIBERAL ARTS: Anthropology: | |
|---|---|
| Bondar, Gregory | G |
| Hirth, Kenneth | F |

| ENVIRONMENTAL RESOURCES RESEARCH INSTITUTE: | |
|---|---|
| Burgos, William | F |
| Tuntoulavest, Muruk | G |

| OFFICE OF ENVIRONMENTAL HEALTH AND SAFETY | |
|---|---|
| Bertocchi, Dave | S |
| Boeldt, Eric | S |
| Dunkelberger, Russ | S |
| Hollenbach, Don | S |
| Linsley, Mark | S |
| Morlang, Suzanne | S |

| COLLEGE OF HUMAN DEVELOPMENT Biobehavioral Health Program: | |
|---|---|
| Hon, Kyung-An | F |
| Lenn, Hynn-Gwan | G |

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

| INDUSTRIES, ETC. | |
|---|---|
| Bettis Labs, Westinghouse | Mike Barry<br>Tom Conroy<br>M. A. El-Ganayni<br>John Snyder |
| Bio-Pore, Inc. | Steve Schwartz |
| DURECT Corporation | Tom Siacotos |
| Eagle-Picher | Monte Hart<br>Jerry Houdyshell<br>Dennis Manning<br>Ralf Surmann |
| Exelon | Dave Poulin<br>Hari Sharma |
| Fairchild Corporation, Mountaintop, PA (formerly Intersil) | Frank Kalkbrenner<br>Joe Macieunas |
| Institut für Sicherheitsforschung, Germany | Jurgen Böhmut |
| Institute für Ionestrahlphysik and Materialforschung, Germany | Gerhard Brauer |
| Instituto de Fischia, Rio Grande do Sul, Brasil | D.S.B. Legoas |
| Instituto de Fisica, Sao Paulo, Brasil | E. L. Amaral |
| Lockheed-Martin | Robert Gigliuto |
| Northeast Technology Corporation | Matt Harris<br>Ken Lindquist<br>Doug Vonada |
| Oglevee, Ltd. | Ed Mikkelsen |
| PPL | John Bokansky<br>Ed Gorski<br>Charlie Purcell |
| Precious Minerals Mining and Refining Corporation | Bill Minor |
| Pro-Clinical, Inc. | Raymond Latshaw<br>Joanne Prine |
| Raytheon | Bruce Black<br>Geoffrey Casteel<br>Angela McMaster |
| Raytheon Systems Company | Ed Craig |
| SAIC | Ed Draper |
| St. Louis Metallizing Company | Klaus Dobler |
| Suntronics, Inc. | David Ripley |
| SUTI-ASIT, Switzerland | Heiner Doelle |
| Synetix | Roy Dobson |
| Transnucleaire, France | Gilles Bonnet<br>Rene Chiocca<br>Philippe Morin<br>Philippe Naigeon |
| Tru-Tec | Mike Flenniken<br>Jerre Kolek |
| TRW | Russ Graham<br>Don Randall |
| TTH, Inc. | Triem Hoang |
| University of Maryland | Robert Rasera |

# APPENDIX B
## FORMAL TOUR GROUPS

| Group Name | Date | # Visitors |
|---|---|---|
| PSU student | 07/01/00 | 1 |
| Bill Siman | 07/05/00 | 1 |
| IKON | 07/05/00 | 1 |
| (PGSAS) | 07/05/00 | 34 |
| (PGSAS) | 07/06/00 | 34 |
| Civil & Environ. Eng. Mtg. with Dr. Catchen | 07/07/00 | 2 |
| Smithlings | 07/07/00 | 2 |
| CCP-25-OPP | 07/11/00 | 2 |
| Marshall Space Fight Center NASA | 07/11/00 | 1 |
| PREF | 07/11/00 | 14 |
| Chmielewski | 07/11/00 | 1 |
| Personal | 07/13/00 | 2 |
| Reinert | 07/13/00 | 1 |
| Personal | 07/13/00 | 2 |
| Ulster Project | 07/13/00 | 2 |
| Student - Nuc E 307 | 07/14/00 | 1 |
| Friend Visiting PSU | 07/14/00 | 1 |
| Michelle Ripka | 07/17/00 | 1 |
| Hoag's Catering | 07/17/00 | 2 |
| Stone Valley Day Camp | 07/18/00 | 12 |
| Hoag's Catering | 07/18/00 | 1 |
| Hoags | 07/18/00 | 3 |
| Vet. Science | 07/19/00 | 2 |
| Sam Levine - Personal | 07/19/00 | 2 |
| VIEW (Vision in Engineering Week) | 07/20/00 | 22 |
| OPP | 07/20/00 | 2 |
| BEST (Business Eng. Science & Technology) | 07/21/00 | 26 |
| EHS/ Police Services | 07/24/00 | 1 |
| Lawrence Livermore Nat Lab - Visitor | 07/24/00 | 1 |
| Spend a Summer Day | 07/24/00 | 8 |
| Forklifts, Inc | 07/26/00 | 1 |
| VIEW Group 2 | 07/28/00 | 10 |
| Davison Family | 07/31/00 | 1 |
| Visitor from Fuel Science | 07/31/00 | 1 |

| Group Name | Date | # Visitors |
|---|---|---|
| Spend a Summer Day | 07/31/00 | 17 |
| Girl Scouts | 08/01/00 | 65 |
| Chemical Engineering | 08/02/00 | 1 |
| Nuclear Technolgy Course | 08/02/00 | 10 |
| VIEW Group 3 | 08/03/00 | 22 |
| Ken's Wife | 08/04/00 | 1 |
| Spend a Summer Day | 08/04/00 | 18 |
| Grads and Families | 08/05/00 | 7 |
| Dept. Of Defense | 08/08/00 | 2 |
| OPP | 08/08/00 | 3 |
| Adventure Day Camp | 08/08/00 | 15 |
| GeoSciences Dept | 08/08/00 | 1 |
| Supply Siource/ Office Store | 08/10/00 | 1 |
| OPP | 08/11/00 | 1 |
| New Student | 08/11/00 | 1 |
| OPP | 08/14/00 | 2 |
| Public Relations | 08/15/00 | 2 |
| Boy Scout Troop 6 (Berwick) | 08/15/00 | 10 |
| Marcia Coleman | 08/15/00 | 1 |
| OPP | 08/15/00 | 1 |
| Disc Riter | 08/15/00 | 1 |
| Dr. Kenney's Nephew | 08/17/00 | 1 |
| Civil Engr. | 08/18/00 | 2 |
| Nuc E 0025 | 08/21/00 | 17 |
| BM Kramer | 08/22/00 | 1 |
| BM Kramer | 08/22/00 | 1 |
| Chemistry | 08/24/00 | 1 |
| OTC | 08/25/00 | 2 |
| Freshman Seminar | 08/29/00 | 16 |
| Vet Science | 08/29/00 | 2 |
| PSU Outreach Magazine | 08/31/00 | 1 |
| PSU student (to see backscatter device) | 08/31/00 | 1 |
| Freshman Seminar | 09/05/00 | 1 |
| Student Tours | 09/06/00 | 1 |

# APPENDIX B
## FORMAL TOUR GROUPS

| Group Name | Date | # Visitors |
|---|---|---|
| NucE Student Tour | 09/06/00 | 1 |
| Houser Vending | 09/06/00 | 3 |
| Prospective Students | 09/06/00 | 1 |
| TTH Research | 09/08/00 | 1 |
| NETCO | 09/08/00 | 1 |
| OPP | 09/11/00 | 6 |
| EHS (PPC Plan Visit) | 09/11/00 | 1 |
| Mech & Nuc Eng Dept speaker | 09/11/00 | 2 |
| PSU Students | 09/11/00 | 1 |
| Nuc E 301 - PSU | 09/12/00 | 1 |
| OPP - Job Review Roofers | 09/13/00 | 3 |
| Tru Tech | 09/13/00 | 1 |
| Chemical Eng Dept Prof - Meeting | 09/15/00 | 2 |
| Environmental Health & Safety visitor | 09/15/00 | 1 |
| Personal - walk in | 09/18/00 | 2 |
| Telecommunications | 09/18/00 | 2 |
| Bell Air | 09/19/00 | 1 |
| OPP | 09/19/00 | 2 |
| Neighborhood Teachers | 09/19/00 | 4 |
| Nuc E 301 | 09/20/00 | 13 |
| CLC Charter School | 09/22/00 | 24 |
| Veterinary Science | 09/22/00 | 2 |
| Parents Weekend Open House | 09/23/00 | 393 |
| Precious Mineral Mining & Refining Corp | 09/27/00 | 1 |
| Chem 405 student | 09/29/00 | 1 |
| OPP | 09/29/00 | 1 |
| OPP | 10/02/00 | 2 |
| Nuclear Measurement wk with Dr. Klevans | 10/03/00 | 2 |
| PSU - Parking Office | 10/03/00 | 1 |
| Exxon - wk with Dr. Klevans | 10/04/00 | 1 |
| Supply Source - Furniture and curtins | 10/04/00 | 1 |
| Rick @ (Endevco) | 10/05/00 | 1 |
| Prospective Students | 10/05/00 | 1 |
| Dave's Offices Hours Nuc E 301 | 10/05/00 | 2 |

| Group Name | Date | # Visitors |
|---|---|---|
| Supply Source | 10/06/00 | 1 |
| Supply Source | 10/06/00 | 2 |
| Centre County Christian Academy | 10/09/00 | 20 |
| Hoags Catering | 10/10/00 | 1 |
| Huag's Catering | 10/10/00 | 1 |
| Computer Support from Nuc E dept | 10/11/00 | 1 |
| Freshman Seminar - PSU Students | 10/11/00 | 19 |
| Dept Seminar Speaker | 10/12/00 | 1 |
| Shane's Visitors | 10/13/00 | 2 |
| Flying Farmers | 10/14/00 | 28 |
| Dr. Jester's Family | 10/16/00 | 3 |
| Don McCann | 10/17/00 | 1 |
| ANS Conference 2002 Committee | 10/17/00 | 2 |
| Seminar Speaker | 10/19/00 | 1 |
| Emergency Planning MTG | 10/20/00 | 2 |
| OPP | 10/20/00 | 2 |
| PSU Student - ME 83 | 10/23/00 | 1 |
| Helton - Family Tour | 10/24/00 | 3 |
| Veterinary Science, experimenters | 10/25/00 | 2 |
| Orkin - Bugs | 10/26/00 | 1 |
| Students/ Advising | 10/27/00 | 2 |
| Giddings & Assc. (Water Authority) | 10/27/00 | 1 |
| Engineering Open House | 10/28/00 | 63 |
| Personal Tour Friends | 10/28/00 | 4 |
| Halloween Party | 10/31/00 | 3 |
| Former Grad Student | 10/31/00 | 1 |
| ME + Nuc | 11/01/00 | 1 |
| Ritenour Health Center | 11/02/00 | 2 |
| Charter School | 11/03/00 | 23 |
| Center for Academic Computing | 11/03/00 | 6 |
| Engr. Prospective Students | 11/03/00 | 2 |
| Nuc E 401 | 11/06/00 | 11 |
| Nuc E 401 | 11/10/00 | 9 |
| OPP | 11/10/00 | 3 |

# APPENDIX B
## FORMAL TOUR GROUPS

| Group Name | Date | # Visitors |
|---|---|---|
| Hlstead's | 11/10/00 | 3 |
| Nuc E Prosective Students | 11/13/00 | 3 |
| NRC/DEP | 11/15/00 | 2 |
| Haungs Wife | 11/15/00 | 1 |
| Nuc E 301 | 11/15/00 | 1 |
| Food Science 413 | 11/16/00 | 21 |
| Food Science/STS 105 | 11/17/00 | 18 |
| Personal | 11/20/00 | 1 |
| Chem Tech | 11/20/00 | 1 |
| Defense Nuclear Safety Board | 11/21/00 | 2 |
| Jaclyn Adamonis Tour | 11/21/00 | 1 |
| Byong-Hun Jeon | 11/22/00 | 1 |
| Perkin Elmer | 11/27/00 | 1 |
| Abington Heights Science Fair Project | 11/27/00 | 2 |
| Prospective Student | 11/27/00 | 2 |
| Conemaugh Valley HS | 11/28/00 | 20 |
| Hoag's | 11/29/00 | 1 |
| FERMI | 11/29/00 | 4 |
| Hoag's Catering | 11/29/00 | 1 |
| Hoag's Catering | 11/29/00 | 1 |
| Engr 100S | 11/30/00 | 15 |
| SpCom 15 | 12/01/00 | 1 |
| John Lathrop | 12/01/00 | 1 |
| UVA Group | 12/03/00 | 6 |
| OPP | 12/04/00 | 1 |
| Eng 202C | 12/04/00 | 1 |
| OPP | 12/11/00 | 1 |
| Johnsons Wax | 12/11/00 | 1 |
| OPP | 12/12/00 | 2 |
| Nuc E 470 | 12/12/00 | 1 |
| OPP | 12/13/00 | 1 |
| OPP | 12/14/00 | 1 |
| Vet Science | 12/14/00 | 2 |
| Dave's Friend | 12/19/00 | 1 |

| Group Name | Date | # Visitors |
|---|---|---|
| Holiday Party Attendees | 12/19/00 | 2 |
| Wods - Personal (Air Force) | 12/19/00 | 1 |
| OPP | 12/20/00 | 3 |
| OPP | 12/20/00 | 1 |
| Loudon County Day School | 12/20/00 | 1 |
| Parking Office | 12/20/00 | 1 |
| OPP | 12/20/00 | 1 |
| Kulp Family | 12/24/00 | 2 |
| Nuclear Safety Center Intern | 01/03/01 | 3 |
| Family Tour Wendy D. | 01/03/01 | 1 |
| Arcbaogoly tour | 01/04/01 | 1 |
| Hoags | 01/09/01 | 2 |
| MPM Technologies | 01/09/01 | 1 |
| Hoags | 01/09/01 | 2 |
| OPP | 01/10/01 | 2 |
| NUC E 597D | 01/10/01 | 2 |
| Perkin Elmer | 01/10/01 | 1 |
| OPP | 01/11/01 | 2 |
| Perspective Student | 01/11/01 | 1 |
| Family tour - Wendy D. | 01/12/01 | 2 |
| Personal tour Jill Buchanan | 01/12/01 | 1 |
| MRL Prospective Experimenter | 01/16/01 | 1 |
| OPP | 01/16/01 | 1 |
| Eaken Family Tour | 01/18/01 | 2 |
| Faculty Meeting | 01/19/01 | 1 |
| Hot Cell Charpy Tester | 01/22/01 | 1 |
| DEP | 01/23/01 | 1 |
| Personal Tour | 01/24/01 | 1 |
| OPP | 01/24/01 | 2 |
| Ag & Bio Engr. Tour | 01/24/01 | 2 |
| PP&L | 01/25/01 | 2 |
| Home Educators | 01/25/01 | 3 |
| Personal Tour | 01/25/01 | 1 |
| Friend/personal tour | 01/25/01 | 1 |

# APPENDIX B
## FORMAL TOUR GROUPS

| Group Name | Date | # Visitors |
|---|---|---|
| FBI interview | 01/30/01 | 1 |
| Beam Lab research | 02/02/01 | 1 |
| Strange Family | 02/05/01 | 3 |
| IE 408W | 02/07/01 | 25 |
| IE 408W | 02/08/01 | 25 |
| Office of Administrative systems | 02/08/01 | 1 |
| IE 408 W | 02/08/01 | 26 |
| Morgan State University | 02/09/01 | 2 |
| Dave's Friend | 02/10/01 | 1 |
| OPP | 02/12/01 | 1 |
| Ag & Bio Engineering | 02/13/01 | 1 |
| Nuc E 420 | 02/13/01 | 1 |
| University Police Training | 02/14/01 | 8 |
| Punxsutawney Area HS | 02/15/01 | 10 |
| Ken's Wife | 02/15/01 | 1 |
| OPP | 02/15/01 | 1 |
| Wilkes College | 02/16/01 | 9 |
| Paula Crust & Friend | 02/16/01 | 2 |
| ELECTRIC MOTORS SYSTEM TOUR | 02/16/01 | 1 |
| Future Student (PSU Engr) | 02/16/01 | 4 |
| OPP | 02/20/01 | 3 |
| GRADUATE STUDENT FAMILY TOUR | 02/21/01 | 2 |
| OPP | 02/21/01 | 4 |
| University Police Training | 02/21/01 | 11 |
| University Police Training | 02/21/01 | 15 |
| ZILKA TOUR | 02/22/01 | 1 |
| EHS | 02/22/01 | 2 |
| EMS | 02/23/01 | 1 |
| PEMA INSTRUCTION GROUP | 02/23/01 | 2 |
| PEMA TRAINING | 02/24/01 | 21 |
| HOAG'S CATERING | 02/24/01 | 1 |
| HOAG'S CATERING | 02/24/01 | 1 |
| PEMA TRAINING | 02/25/01 | 19 |
| HOAG'S CATERING | 02/25/01 | 1 |

| Group Name | Date | # Visitors |
|---|---|---|
| HOAG'S CATERING | 02/25/01 | |
| NE 496 | 02/25/01 | 1 |
| INTERVIEWEE | 02/26/01 | 1 |
| MG INDUSTRIES | 02/27/01 | 1 |
| OPP | 02/27/01 | 2 |
| MG INDUSTRIES | 03/01/01 | 1 |
| EXELON | 03/01/01 | 1 |
| WILTROM (PROSPECTIVE GRAD STUDENT) | 03/02/01 | 1 |
| CENTRAL PA INSTITUTE | 03/02/01 | 17 |
| JOE BONNER | 03/02/01 | 1 |
| REALTORS ASSOC. | 03/02/01 | 2 |
| PERSONAL | 03/02/01 | 5 |
| BESTLINE LEASING | 03/05/01 | 1 |
| STUDENT TOUR | 03/05/01 | 1 |
| OPP | 03/06/01 | 1 |
| EMS | 03/09/01 | 3 |
| Student-advisee | 03/10/01 | 1 |
| PJSAHS | 03/12/01 | 10 |
| PSU Visitors | 03/13/01 | 1 |
| Salvage | 03/14/01 | 1 |
| OPP | 03/15/01 | 2 |
| Interviewee | 03/15/01 | 1 |
| Kenney Family Member | 03/15/01 | 2 |
| Exelon | 03/16/01 | 1 |
| Telecom | 03/16/01 | 1 |
| Boy Scouts | 03/17/01 | 43 |
| Student | 03/17/01 | 1 |
| Parking Office | 03/19/01 | 1 |
| Salvage | 03/20/01 | 1 |
| USOPM Interview | 03/20/01 | 1 |
| Irvin Hall Interest House | 03/20/01 | 7 |
| USOPM Interview | 03/21/01 | 1 |
| Greensburg Salem HS | 03/21/01 | 16 |
| Prospective Student | 03/22/01 | 1 |

# APPENDIX B
## FORMAL TOUR GROUPS

| Group Name | Date | # Visitors |
|---|---|---|
| Westinghouse | 03/22/01 | 1 |
| Prospective Student | 03/23/01 | 1 |
| Dr. W's Wife | 03/23/01 | 1 |
| Open House | 03/24/01 | 42 |
| Personal tour | 03/24/01 | 2 |
| Glendale HS | 03/28/01 | 43 |
| Tyrone Middle School | 03/29/01 | 42 |
| Tyrone Middle School | 03/29/01 | 34 |
| Partylite | 03/29/01 | 1 |
| Neil Tondreas - Seminar Speaker | 03/29/01 | 1 |
| Student | 03/31/01 | 1 |
| Graduate Information Weekend | 03/31/01 | 10 |
| Graduate Information Weekend | 03/31/01 | 10 |
| Interviewee | 04/02/01 | 1 |
| Westinghouse HR | 04/02/01 | 1 |
| Grove City College | 04/03/01 | 6 |
| Personal Tour (Marcia's Friend) | 04/03/01 | 1 |
| Food Science Department | 04/04/01 | 1 |
| Bellefonte High School | 04/04/01 | 6 |
| Daniel Boone HS | 04/05/01 | 16 |
| RUS | 04/05/01 | 1 |
| Elderhostel | 04/05/01 | 33 |
| Prospective Student | 04/06/01 | 1 |
| Elkland HS | 04/06/01 | 27 |
| Pat Loftus (OEA) & Family | 04/09/01 | 6 |
| Hoags Catering | 04/10/01 | 2 |
| Supply Source | 04/10/01 | 3 |
| Gemtech Corp. | 04/11/01 | 1 |
| Hoag Catering | 04/11/01 | 2 |
| OPP | 04/11/01 | 1 |
| OHR | 04/11/01 | 1 |
| RTP Corp. | 04/12/01 | 1 |
| Prospective Students | 04/13/01 | 4 |
| U.S. OPM | 04/16/01 | 1 |

| Group Name | Date | # Visitors |
|---|---|---|
| Dominion | 04/16/01 | 2 |
| Air Force | 04/17/01 | 3 |
| M & NE | 04/17/01 | 1 |
| PSU-Res Life | 04/17/01 | 4 |
| Dave's Friend | 04/17/01 | 1 |
| Retired Faculty | 04/18/01 | 1 |
| Mifflin County Christian Academy | 04/19/01 | 17 |
| OPP | 04/19/01 | 1 |
| Hot Cell Lab | 04/19/01 | 2 |
| Grad Student - NUCE | 04/19/01 | 1 |
| Argon Truck Driver | 04/20/01 | 1 |
| Klevans Family | 04/23/01 | 1 |
| SRTE | 04/24/01 | 1 |
| Marion Center HS | 04/25/01 | 8 |
| Dan Kolbe | 04/25/01 | 1 |
| Allensville Planning Mill | 04/25/01 | 3 |
| Take Our Daughters to Work | 04/26/01 | 7 |
| OPP | 04/26/01 | 1 |
| Take Our Daughters to Work | 04/26/01 | 7 |
| Take Our Daughters to Work | 04/26/01 | 2 |
| St. Mary's Area High School | 04/27/01 | 33 |
| Student | 04/30/01 | 1 |
| Personal Tour | 05/01/01 | 2 |
| Personal Tour | 05/01/01 | 1 |
| Student | 05/04/01 | 1 |
| Student | 05/05/01 | 1 |
| NRC/ARL/Penn State | 05/07/01 | 4 |
| Brother (Personal Tour) | 05/08/01 | 1 |
| ACME Trucking | 05/10/01 | 1 |
| Cambria Heights H.S. | 05/10/01 | 44 |
| Potential Student/Former Student | 05/10/01 | 2 |
| OPP | 05/10/01 | 1 |
| Friend - Personal Tour | 05/11/01 | 1 |
| Personal Tour - Family | 05/11/01 | 3 |

# APPENDIX B
## FORMAL TOUR GROUPS

| Group Name | Date | # Visitors |
|---|---|---|
| Rankin | 05/11/01 | 1 |
| Chris Gouvernor IE 408 | 05/11/01 | 4 |
| Dave's Family | 05/11/01 | 7 |
| Family - Personal Tour | 05/11/01 | 2 |
| PJAS - Tammy Young | 05/14/01 | 1 |
| Mary Lou Gougar Thesis Committee | 05/15/01 | 3 |
| NBL Modelling MTG | 05/15/01 | 1 |
| OPP/ADA | 05/16/01 | 4 |
| Red Lion Christian Academy | 05/17/01 | 6 |
| Personal Tour - Finance | 05/17/01 | 1 |
| Spring Grove High School | 05/18/01 | 2 |
| Danville High School | 05/22/01 | 30 |
| Personal Tour | 05/22/01 | 1 |
| OPP | 05/23/01 | 1 |
| Berwick H.S. | 05/24/01 | 17 |
| EMS | 05/24/01 | 1 |
| OPP | 05/25/01 | 1 |
| OPP | 05/25/01 | 2 |
| OPP | 05/25/01 | 2 |
| Personal Tour | 05/25/01 | 1 |
| Penn State Mont Alto Faculty Tour | 05/29/01 | 1 |
| Tsukimura's | 06/01/01 | 2 |
| OPP | 06/02/01 | 6 |
| Tsukimura | 06/03/01 | 1 |
| Student | 06/04/01 | 1 |
| Health & Human Development | 06/04/01 | 1 |
| OPP | 06/05/01 | 2 |
| PA Business Central - Reporter | 06/05/01 | 1 |
| ITMNR - 4 | 06/05/01 | 51 |
| OPP | 06/06/01 | 2 |
| OPP | 06/08/01 | 1 |
| NUCE 297/497 | 06/11/01 | 10 |
| OPP | 06/12/01 | 1 |
| Girlz in Engr. | 06/12/01 | 34 |
| OPP | 06/12/01 | 1 |
| RAMP Course | 06/12/01 | 1 |
| Girlz in Engineering | 06/13/01 | 30 |
| Personal | 06/13/01 | 1 |
| Personal | 06/13/01 | 1 |
| Dean's Office | 06/13/01 | 1 |
| OPP | 06/14/01 | 2 |
| Cerk Gules - Personal | 06/14/01 | 1 |
| OPP | 06/15/01 | 1 |
| CDFC | 06/15/01 | 16 |
| Tour Group Total | | 2506 |