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 99-00
PSBR Technical Specifications 6.6.1
License R-2, Docket No. 50-5

December 8, 2000

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, 1999 through June 30, 2000, 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-Fifth 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 99-00
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 8 AM - 8 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, 1999 and June 30, 2000, the PSBR was

| | | |
|---|---|---|
| critical for | 941 hours | or 3.4 hrs/shift |
| subcritical for | 455 hours | or 1.6 hrs/shift |
| used while shutdown for | 535 hours | or 1.9 hrs/shift |
| not available | 27 hours | or 0.1 hrs/shift |
| Total usage | 1958 hours | or 7.0 hrs/shift |

The reactor was pulsed a total of 75 times with the following reactivities:

| | |
|---|---|
| < $2.00 | 8 |
| $2.00 to $2.50 | 35 |
| > $2.50 | 32 |

The square wave mode of operation was used 28 times to power levels between 100 and 500 KW.

Total energy produced during this report period was 419 MWH with a consumption of 22 grams of U-235.

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

The 4 unplanned shutdowns during the July 1, 1999 to June 30, 2000 period are described below.

July 13, 1999 – The reactor operator scrammed the reactor as per procedure when a rabbit capsule failed to return from the reactor core to the laboratory terminus. The capsule was retrieved intact without incident. It was found that a flexible hose in the system could partially collapse when the system was cycled. That hose section was replaced with a stiffer hose.

December 7, 1999 – A Wide Range/Power Range power spread stepback occurred during a reactor startup when the power spread exceeded the 200 kW setpoint. A core loading change had just been made and as a result it was found that the flux was shifted towards the Wide Range neutron detector at the rear of the core and away from the Power Range gamma detector on the east side of the core. Following the event, the power spread setpoint was changed from 200 kW to 300 kW.

December 9, 1999 – The reactor was shutdown by the operator when during a startup, the reactor prematurely went into 3 rod auto when the F2 button was pushed to select auto mode. Normally four additional keystrokes would be needed to initiate entry into 3 rod auto. The investigation concluded that the event was of an unknown origin.

June 26, 2000 – The senior reactor operator scrammed the reactor when a larger than expected power increase (180 watts to 280 watts) was noted when an experimenter's computer locked up driving an "experimental changeable reactivity device" toward its upper limit from it's bottom position in the reactor's central thimble. Such possible experimental performance had been anticipated and the Wide Range stepback setpoints had been lowered to 20 kW as part of the experiment requirement.

**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 December 7, 1999, six fuel elements were added to the periphery of core loading 50 to establish new loading 51. This core change was done to increase excess reactivity to compensate for fuel burnup. A 50.59 review found core parameters for loading 51 to be within the limits of the Safety Analysis Report and the Tech Specs. Therefore, no unreviewed safety issues were identified.

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 -

An Experimental Changeable Reactivity Device #2 (ECRD #2) underwent a 50.59 review on January 18, 2000, Penn State Reactor Safeguards Committee review on April 4, 2000, and experimental qualification by way of an experiment during May 10 to May 15, 2000. The ECRD #2 operates at speeds up to 4.5 inches/sec over a stroke of 15 inches in the central thimble of the reactor core. The poison is primarily cadmium and the total reactivity worth is ~$1.00.

ECRD #2 is moved on demand from an experimenter's computer separate from the normal reactor control system, to simulate the neutronics portion of BWR behavior during investigations of thermal-hydraulic stability characteristics.

The 50.59 review determined that the rates of change of reactivity and power are well within the analysis covered by the Tech Specs (TS) and Safety Analysis Report (SAR). The probability of occurrence or the consequences of an accident or malfunction of equipment important to safety previously evaluated in the SAR is not increased. The possibility for an accident or malfunction of a different type than any previously evaluated in the SAR is not created. The margin of safety as defined in the basis for any TS is not reduced. Experiments performed utilizing the ECRD #2 as described within this review do not involve an unreviewed safety question.

**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 Health Physics Office for disposal with the waste from other campus laboratories. Liquid waste disposal techniques include storage for decay, release to the sanitary sewer as per 10 CFR 20, and solidification for shipment to licensed disposal sites.

Gaseous

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 Health Physics staff during the summer of 1986. Measurements were made for conditions of low and high power runs simulating typical operating cycles. Based on these measurements, an annual release of between 320 mCi and 968 mCi of Ar-41 is calculated for July 1, 1999 to June 30, 2000, resulting in an average concentration at ground level outside the reactor building that is 0.5 % to 1.5 % 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 366 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 366 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 in negligible. When beam port #7 was used, the door to beam port #4 was closed and an aluminum cap was installed inside the end of this beam port to mitigate any further Ar-41 releases. The estimated Ar-41 production in beam port #4 for reactor runs using beam port #7 is 12 mCi. It is assumed that this argon-41 decayed in place since Radiation Protection Office air measurements taken during beam port #7 operation found no presence of Ar-41. Reactor runs with beam port #4 door open were minimal, and the estimated argon-41 production is estimated to be 3 mCi.. With the aforementioned aluminum cap in place, it is assumed that this Ar-41 decayed 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 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 55821 pCi/l (the average for July 1, 1999 to June 30, 2000) the tritium activity released from the ventilation system would be 989 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 showed no detectable $^3H$. Thus, there is probably very little $^3H$ recycled into the pool by way of the air conditioner condensate and all evaporation can be assumed to be released.

| | |
|---|---|
| $^3H$ released | 989 μC |
| Average concentration, unrestricted area | 1.57 x $10^{-13}$ μCi/ml |
| Permissible concentration, unrestricted area | 1 x $10^{-7}$ μCi/ml |
| Percentage of permissible concentration | 1.57 x $10^{-4}$ % |
| Calculated effective dose, unrestricted area | 7.8 x $10^{-5}$ 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, 1999 to June 30, 2000 period.

| | 3rd Qtr '99 | 4th Qtr '99 | 1st Qtr '00 | 2nd Qtr '00 | Total |
|---|---|---|---|---|---|
| Fence North | 29.8 | 27.4 | 31.5 | 31.5 | 120.2 |
| Fence West | 28.5 | 26.2 | 29.0 | 30.3 | 114.0 |
| Fence East | 31.0 | 27.7 | 29.1 | 33.5 | 121.3 |
| Fence South | 26.3 | 26.6 | 26.9 | 30.2 | 110.0 |
| Control | 23.8 | 30.2 | 24.2 | 30.1 | 108.3 |
| Control | 26.7 | 22.9 | 21.2 | 28.5 | 99.3 |

**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.

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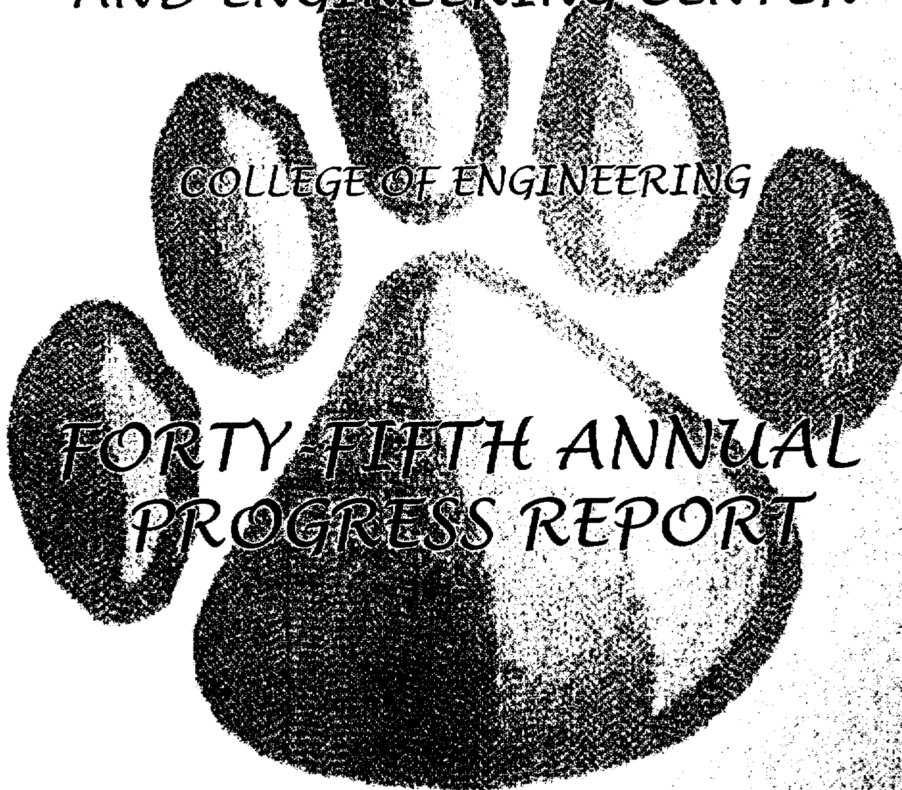
# THE PENNSYLVANIA STATE UNIVERSITY'S

# RADIATION SCIENCE AND ENGINEERING CENTER

COLLEGE OF ENGINEERING



# FORTY-FIFTH ANNUAL PROGRESS REPORT

NOVEMBER 2000

# FORTY-FIFTH ANNUAL PROGRESS REPORT

# PENN STATE RADIATION SCIENCE AND ENGINEERING CENTER

July 1, 1999 to June 30, 2000

Submitted to:

United States Department of Energy

and

The Pennsylvania State University

By:

C. Frederick Sears (Director)
Alison R. Helton (Co-Editor)
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Radiation Science and Engineering Center
The Pennsylvania State University
University Park, PA 16802

November 2000

Contract DE-AC07-94ID-13223
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U.Ed.ENG 01-54

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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/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, provide services that are essential in meeting research, development, education, and training needs.

The Pennsylvania State University Radiation Science and Engineering Center's Forty-Fifth Annual Progress Report (July 1999 through June 2000) 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 Alison Helton and Sue Ripka who co-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.

*The cover photo is a neutron radioscopic image of a Lion's Paw. The image of the paw was created by milling the design into a 1/2-inch thick aluminum plate. Inside each outline, three areas were milled out and machined in three varying depths. A thin aluminum cover with a gasket was placed over the paw shape and the area was filled with water. The dark areas in the image are the areas of thinnest metal and highest attenuation (most water). The areas where the attenuation is lowest and metal is thickest, (least water) appear lighter.*

# 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 become 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. A review of the utilization data for the last 16 years shows increases in the last three years with a peak this reporting period in areas of time critical, total hours of use, and energy released (MWH).

- A modified reactor core fuel loading (configuration #51) was put into service in December 1999. Six fuel elements were added to the previous configuration #50 to increase core excess reactivity to account for fuel burnup since loading #50 was put into service in October of 1998. Core parameters predicted by fuel management codes were verified by extensive experimental measurements.

- 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 began a major research project using radioscopy for a Bettis Atomic Power Laboratory project involving fluid dynamics.

- A condition reporting form (CRF) system was initiated at the end of the previous reporting year and received enthusiastic staff support and utilization during this reporting year. The CRF system was established to capture facility safety and maintenance issues that may not have been captured and documented under existing maintenance and repair procedures that usually address more major issues. The CRF system provides timely response to staff identified issues (both nuclear and non-nuclear) and provides a historic tracking of system performance problems. Seemingly minor problems that are reported can be precursors to more serious problems that are developing. Thirteen CRFs were filed near the end of the previous 1998-99 reporting year as the system became established. Forty CRFs were filed during the 1999-00 reporting year.

- The Radionuclear Applications Laboratory (RAL) completed a major upgrade of its gamma spectroscopy capabilities with the purchase of new computers and Gamma Vision software. The software is more user friendly than the previous software, increasing staff productivity and also making it easier to train personnel from other university departments to use gamma spectroscopy in their research. An automatic sample changer has been ordered for installation early in the next reporting year.

- Phase I of Dr. Robert Edwards' DOE funded project "Monitoring and Control Research Using a University Research Reactor" was completed. This involved considerable staff efforts in developing an Experimental Changeable Reactivity Device (ECRD #2) for use in the reactor core and interfacing Dr. Edwards' control system with the Penn State thermal-hydraulic test loop.

- Facility service income has supplemented university funds to address facility maintenance needs and upgrades. New air compressors with an air dryer system, new and rebuilt secondary heat exchanger pumps, color coding of all water/air/steam valves throughout the facility are some examples of enhancements. The service income has also allowed for the upgrade of calibration equipment used by the electronics repair shop, purchase of an industrial quality band saw and other equipment for the machine shop, increasing our spare parts inventory of reactor related equipment and improving facility appearance.

# PERSONNEL

# II. PERSONNEL

Wendy Donley, Staff Assistant VI, was on a leave of absence from December 15, 1999 to April 3, 2000. Paula Crust worked in a Wage Payroll position from November 24, 1999 to May 1, 2000 to help with clerical duties during Wendy's absence. Angela Pope was hired into a new Staff Assistant V position on December 3, 1999.

Dan Hughes, Senior Research Assistant/Manager of Engineering Services, resigned on July 30, 1999. Brenden Heidrich, who had been a Senior Reactor Operator, Reactor Intern/Graduate Assistant, filled the vacant position as a Research Assistant.

Jeff Armstrong, Experimental and Maintenance Mechanic, resigned his position on January 21, 2000, to accept another position on campus. The position was not filled, and the facility contracted with the University's Office of Physical Plant to provide janitorial services for the building.

The following personnel worked in work-study/wage payroll positions during the year: Erin Carlin, Dianna Hahn, Kaydee Kohlhepp, and Wayne Nixon assisted Candace Davison in facility educational programs for high school students. The facility's Computer Support Specialist position was held by Jack Lee through May 5, 2000, and was filled by Jeremy Myers on June 16, 2000. Shane Hanna served as a Neutronics Inspection Technician. Lee Armstrong worked as a work-study student in assisting the administrative staff in clerical duties. Chris Andes worked as a work-study student.

The following changes to the membership of the Penn State Reactor Safeguards Committee (PSRSC) were effective on January 1, 2000. Committee Chairman, Warren F. Witzig (Professor Emeritus, Nuclear Engineering, Penn State) left the committee after serving two terms. Current committee member Dhushy Sathianathan became the Chairman. Sandy Rupprecht (Manager of Nuclear Safety Analysis, Westinghouse) left the committee after one term. Theodore C. Dalpiaz (Manager, Nuclear Maintenance, Pennsylvania Power and Light Susquehanna Steam Electric Station) and Alireza Haghighat (Professor, Nuclear Engineering, Penn State) were re-appointed to second terms. Gordon Robinson (Professor Emeritus, Nuclear Engineering, Penn State) and Ira B. McMaster (Deputy Director, Breazeale Reactor – retired) joined the committee on January 1, 2000.

## *TABLE I*

## Personnel

| | Faculty and Staff | Title |
|---|---|---|
| | 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. Helton | Reactor Operator/Research and Service Support Specialist |
| ** | D. E. Hughes | Senior Research Assistant/Manager of Engineering Services (resigned) |
| | J. Lebiedzik | Research Support Technician III |
| ** | G. M. Morlang | Reactor Engineer/Supervisor, Reactor Operations |
| | 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 | |
|---|---|
| J. E. Armstrong | Experimental and Maintenance Mechanic (resigned) |
| R. L. Eaken | Machinist A |

| Wage Payroll/Workstudy | |
|---|---|
| C. Andes | S. Hanna |
| L. Armstrong | K. Kohlhepp |
| E. Carlin | J. Lee |
| D. Hahn | J. Myers |
| | W. Nixon |

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 |
| * | S. Rupprecht | Manager of Nuclear Safety Analysis, Westinghouse |
| | D. Sathianathan | Chairman, Assistant Professor, Engineering Graphics, Penn State |
| | C. F. Sears | Ex-Officio, Director, Penn State Radiation Science and Engineering Center |
| * | W. F. Witzig | Chairman, Professor Emeritus, Nuclear Engineering, Penn State |

* *Served through January 1, 2000*

** *Appointed January 1, 2000*

# Radiation Science & Engineering Center Personnel Chart

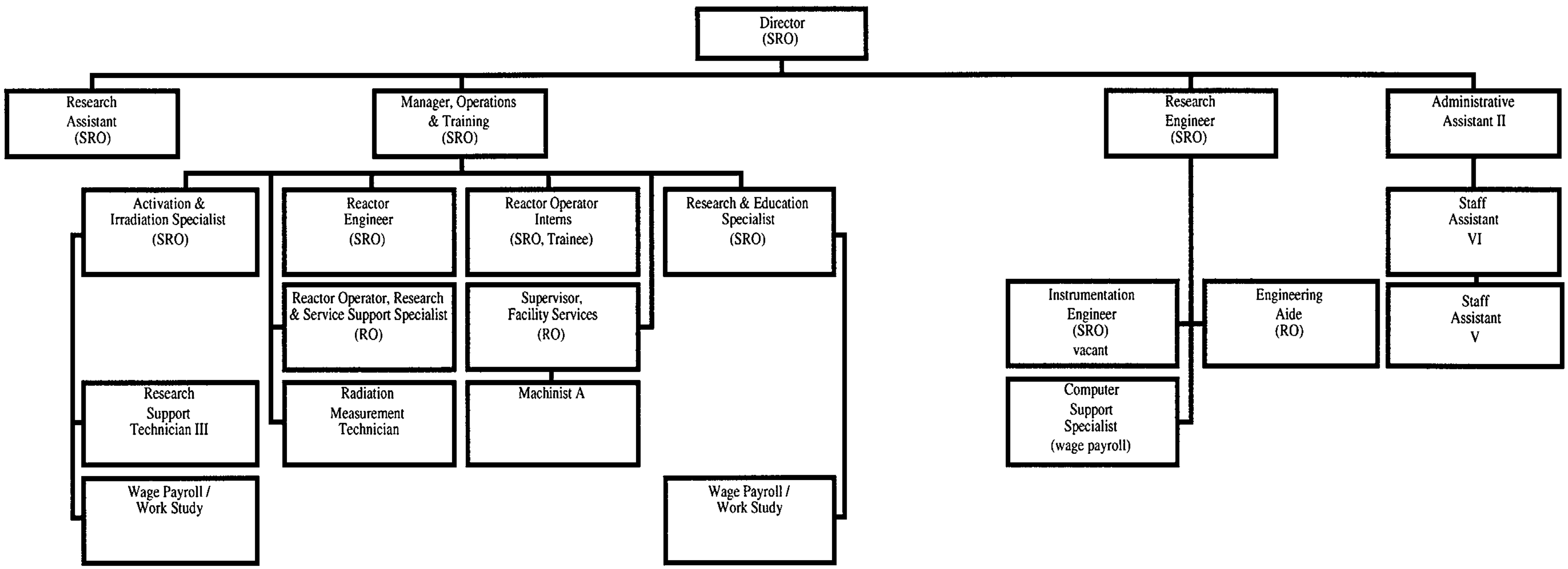



**Figure 1**

# 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 $6 \times 10^{16}$ n/cm$^2$/sec with a pulse width of 15 msec at $^1/_2$ 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.

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 Richard Ladun of NRC Region I on October 6 -7, 1999. This inspection covered activities authorized by Penn State's Special Nuclear Materials License. No items of non-compliance were identified.

On November 16-17, 1999, 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 Patrick S. Brady, Nuclear Engineer, GPU Nuclear and Ira B. McMaster, Deputy Director (retired), Penn State Breazeale Nuclear Reactor. The reactor staff is implementing changes suggested by that report, all of which exceed NRC requirements.

*TABLE 2*

**Reactor Operation Data**
**July 1, 1997 - June 30, 2000**

| | | 97-98 | 98-99 | 99-00 |
|---|---|---|---|---|
| A. | Hours of Reactor Operation | | | |
| | 1. Critical | 755 | 895 | 941 |
| | 2. Subcritical | 517 | 396 | 455 |
| | 3. Fuel Movement | 28 | 17 | 46 |
| B. | Number of Pulses | 56 | 29 | 75 |
| C. | Number of Square Waves | 40 | 14 | 28 |
| D. | Energy Releases (MWH) | 326 | 365 | 419 |
| E. | Grams U-235 Consumed | 17 | 17 | 22 |
| F. | Scrams | | | |
| | 1. Planned as Part of Experiments | 5 | 9 | 11 |
| | 2. Unplanned - Resulting From | | | |
| | a) Personnel Action | 4 | 2 | 1 |
| | b) Abnormal System Operation | 2 | 7 | 1 |

## *TABLE 3*

**Reactor Utilization Data**
**Shift Averages**
**July 1, 1997 - June 30, 2000**

| | | 97-98 | 98-99 | 99-00 |
|---|---|---|---|---|
| A. | Reactor Usage | | | |
| | 1. Hours Critical | 2.6 | 3.3 | 3.4 |
| | 2. Hours Subcritical | 1.8 | 1.5 | 1.6 |
| | 3. Hours Shutdown | 2.0 | 1.5 | 1.9 |
| | 4. Reactor Not Available | 0.4 | 0.2 | 0.1 |
| | TOTAL HOURS PER SHIFT | 6.8 | 6.5 | 7.0 |
| B. | Type of Usage - Hours | | | |
| | 1. Industrial Research and Service | 2.6 | 3.4 | 3.2 |
| | 2. University Research and Service | 1.0 | 0.4 | 0.4 |
| | 3. Instruction and Training | 1.2 | 0.7 | 0.9 |
| | 4. Calibration and Maintenance | 1.9 | 1.9 | 2.3 |
| | 5. Fuel Handling | 0.1 | 0.1 | 0.2 |
| C. | Users/Experiments | | | |
| | 1. Number of Users | 2.4 | 2.4 | 2.7 |
| | 2. Pneumatic Transfer Samples | 0.3 | 0.1 | 0.1 |
| | 3. Total Number of Samples | 3.2 | 2.7 | 3.0 |
| | 4. Sample Hours | 2.6 | 2.8 | 3.0 |
| D. | Number of 8 Hour Shifts | 287 | 273 | 279 |

# 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

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 | 36.5 | Must be less than 6 inches in diameter |
| South Tube 3-inch | 63.0 | Must be less than 3 inches in diameter |
| 10-inch Chamber | 1.4 | Cylinder approximately 10 inches in diameter by 12 inches in height |
| GammaCell Dry Cell Irradiator | 240.0 | Cylinder approximately 6 inches in Diameter by 7.5 inches in height |
| *as of 7/1/2000 | | |

## TABLE 5

| Cobalt-60 Utilization Data July 1, 1997 – June 30, 2000 | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 97-98 | 97-98 | 98-99 | 98-99 | 99-00 | 99-00 |
| | | **Pool Irradiator** | **GammaCell** | **Pool Irradiator** | **GammaCell** | **Pool Irradiator** | **GammaCell** |
| A. | Time Involved (Hours) | | | | | | |
| | 1. Set-Up/Admin. Time | 35 | 20 | 28 | 30 | 10 | 21 |
| | 2. Total Sample Hours | 1318 | 696 | 1473 | 978 | 1040 | 563 |
| | | | | | | | |
| B. | Numbers Involved | | | | | | |
| | 1. Samples Containers Run[1] | 1919 | 243 | 1644 | 287 | 742 | 383 |
| | 2. Different Experimenters | 24 | 28 | 12 | 17 | 17 | 23 |
| | 3. Configurations Used | 3 | NA | 3 | NA | 3 | NA |
| | | | | | | | |
| C. | Per Day Averages | | | | | | |
| | 1. Experimenters | 0.4 | 0.4 | 0.4 | 0.4 | 0.2 | 0.5 |
| | 2. Samples | 7.7 | 1 | 6.6 | 1.1 | 2.9 | 1.5 |
| | | | | | | | |

The sample hours for the GammaCell for 1999-2000 would be equivalent to 3,750 sample hours in the large pool irradiation tube.

[1] Note that each sample container may contain multiple samples and that multiple samples may be run together in one batch.

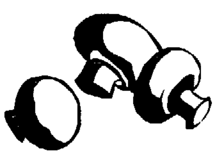
Gamma Irradiation Uses and Examples

**Food Irradiation**

Class Projects and Demonstrations

Beef

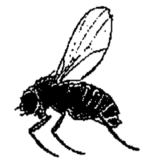
Raspberries



Mushrooms

**Genetic Changes**

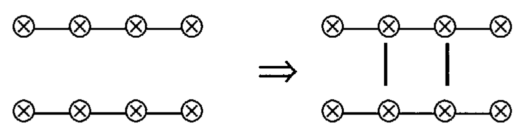
Poinsettias



Fruit Flies

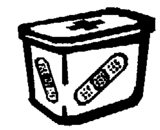
Cells

**Cross-Linking of Polymers**



**Sterilization**

Medical & Laboratory Products



Soil & Leaves for Environmental Research

***Figure 2***

# 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 alone accommodated 2440 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 1999, consisted of an oral examination on abnormal and emergency procedures given by K. E. Rudy and an operating test given by B. J. Heidrich. Operator Intern Dave Werkheiser passed his NRC Senior Rector Operator License examination in April of 2000.

## Governor's School:

The fourteenth session of the Pennsylvania Governor's School for Agricultural Sciences (PGSAS) was held at Penn State's University Park campus during the summer of 1999. Sixty-four high school scholars participated in the five-week program at Penn State. The Governor's School for Agricultural Sciences includes introduction and experience in many different agricultural disciplines. There are several parts of the program including core courses, elective courses and Independent Study Projects (ISP's).

All participants of the Governor's School received a tour of the Reactor facility with some time for hands-on instruction. A fourteen hour elective course, "Nuclear Applications, Learning about the Past and Present", was conducted for 18 scholars. The course was conducted at Penn State's RSEC by Candace Davison along with Erin Carlin, a graduate student in the College of Education, and Nuclear Engineering undergraduate students Kaydee Kohlepp and Dianna Hahn. The Governor's School scholars performed a series of experiments focusing on the fundamentals of radiation interaction and principles of radioisotope applications. Dr. Jack Brenizer provided instruction and a session on neutron imaging. The scholars prepared materials for x-ray and neutron imaging comparisons. They also conducted an experiment with the reactor and participated in a demonstration using materials and the technique of neutron activation analysis.

## 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 700 students and teachers from 24 different educational institutions and 3 colleges came to the RSEC for experiments and instruction (see map). Candace Davison, Erin Carlin and Wayne Nixon were the main instructors for the program. Kaydee Kohlepp and Dianna Hahn lead tours and experiments, and provided information to students concerning their WISER project. 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 Kodak BEST (Business, Science, Engineering and Technology) program for minority students, the High School Summer Internship, SOARS (Special Opportunities and Research for Space), the VIEW program, Women in Science and Engineering (WISE) week, Upward Bound, Pennsylvania Junior Academy of Sciences and other programs associated with campus activities. Fifteen teachers from the Nuclear Science and Technology Workshop received instruction on radiation and nuclear issues and conducted experiments 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.

***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 Mechanical and Nuclear Engineering Department conducted several Open House events for the Parent and Family Weekend, the general public and potential students. Over 400 people participated in Open House and "Spend a Day" experiences.

## Academic Instruction:

The RSEC TRIGA reactor and Cobalt-60 irradiation facilities were used by several Nuclear Engineering courses and courses in other departments of the university.

| Semester | | Course | Instructor | Students | Hours |
|---|---|---|---|---|---|
| Summer | 1999 | NucE 444 – Nuclear Reactor Operations | D. E. Hughes | 2 | 13 |
| Summer | 1999 | SCIED 498B – Nuclear Science and Technology Workshop | J. R. Vincenti<br>C. C. Davison | 15 | 3 |
| Fall | 1999 | Engr. 097 | A. Motta | 19 | 1 |
| Fall | 1999 | NucE 451 – Reactor Physics | R. M. Edwards | 12 | 27 |
| Fall | 1999 | CE 472 W | J. Matson | 24 | 1 |
| Fall | 1999 | Food Science 413 – Science and Technology of Plant Foods | R. B. Beelman | 33 | 2 |
| Spring | 2000 | PSU – 012 | R. M. Edwards | 7 | 1 |
| Spring | 2000 | CI – 295 | E. Carlin | 47 | 3 |
| Spring | 2000 | Food Science 430 – Unit Operation in Food Processing | R. B. Beelman | 3 | 1 |
| Spring | 2000 | Food Science 105 | S. Campbell | 5 | 1 |
| Spring | 2000 | NucE 444 – Nuclear Reactor Operations | C. F. Sears | 3 | 31 |
| Spring | 2000 | NucE 450 – Radiation Detection and Measurement | J. S. Brenizer | 12 | 5 |

## Police Training:

In February of 2000, a total of 35 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.

## Educational Institutions Visiting the RSEC

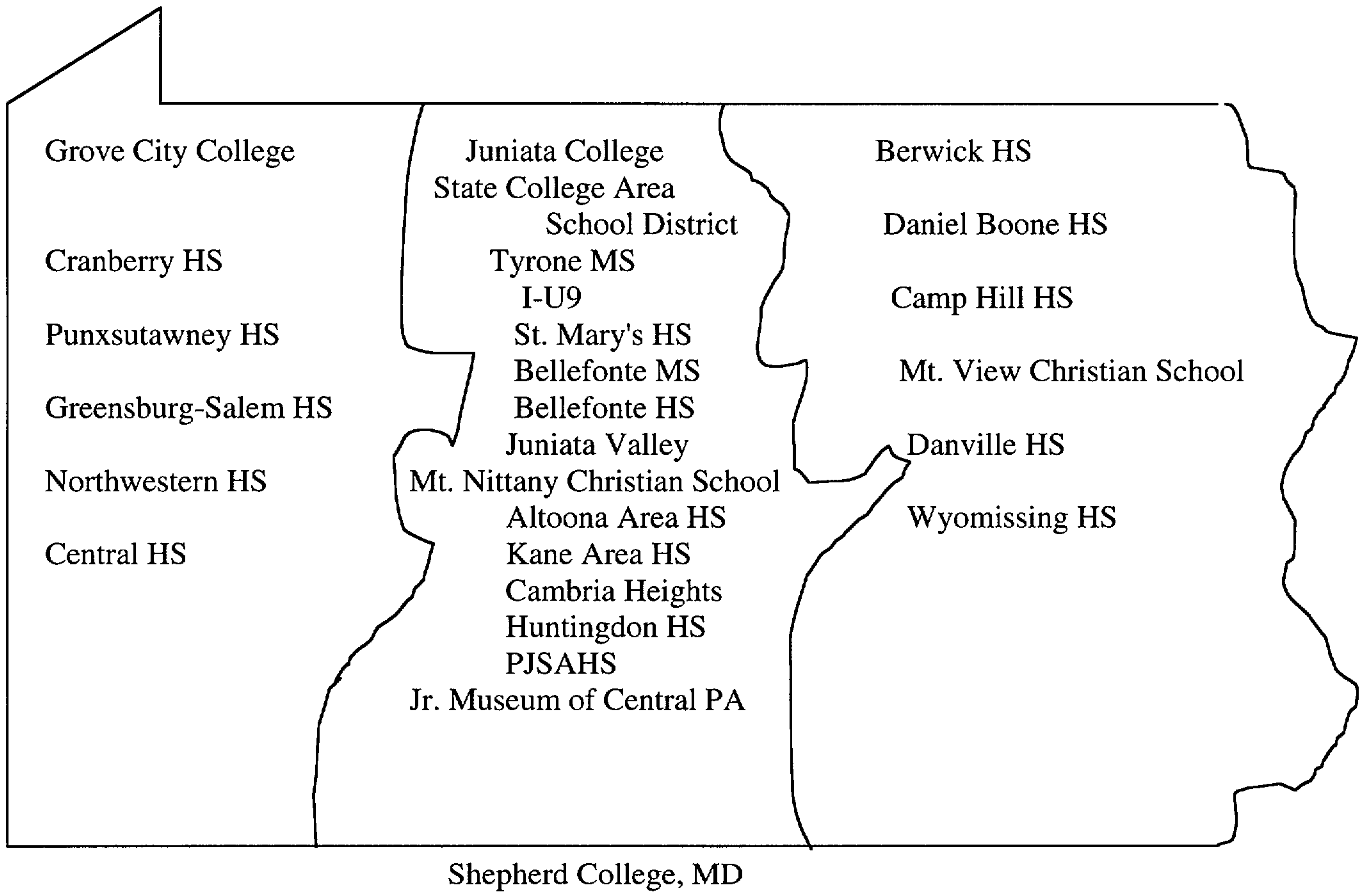



***Figure 3***

# 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 Real Time Neutron Image Intensifier, 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 155, 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 to evaluate two phase flow in a water heat pipe. Additional testing of heat pipes began 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, and Transnucleaire, France.

- 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.

- Work began on an ASTM Divergence and Alignment Indicator (DAI) standard. This work will be continued throughout next year.

# 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. Laboratory personnel support RSEC operations by performing analyses of water, air monitor filters, and other samples as needed. The RAL has increased its gamma spectroscopy capabilities with the purchase of new computers and PerkinElmer's (formerly Ortec) GammaVision software. Currently, we are in the process of purchasing an automatic sample changer to further increase our counting capability.

Services offered by the RAL include analyses of environmental samples for alpha/beta and gamma activities. The RAL also performs analyses in support of the Breazeale Reactor's operations. 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 and when the gross alpha or gross beta action limit is exceeded. 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, 546 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.

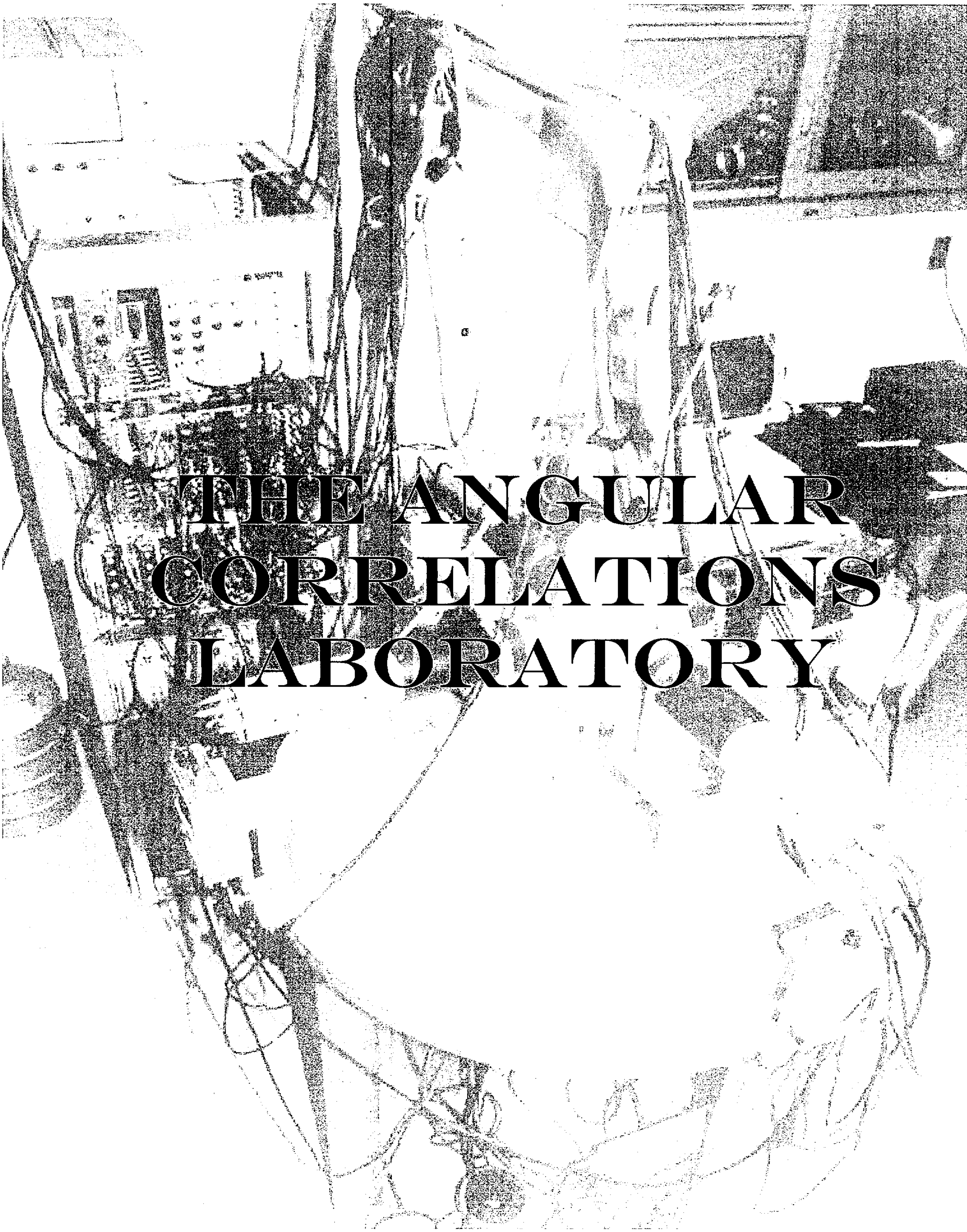
The facility performed 20 isotope production runs of Na-24, Br-82 or Ar-41 for industrial use during the past fiscal year. As needed, the RAL is able to analyze and test chemicals not currently on our approved list.

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.

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. The obsidian samples originate from Central America and the rhyolite samples are collected in the United States. This work is expected to continue for the next year.

The RAL performed irradiation/analysis work for a high school student's science fair project. The student was comparing various pottery samples to determine if they were of the same source site.

An intercomparison study was performed with Cornell University on behalf of Intersil Corporation. A series of sulfur pellets and nickel foils were irradiated to various fluence levels to verify and "normalize" Cornell's fluence levels with those of PSU for semiconductor irradiation.

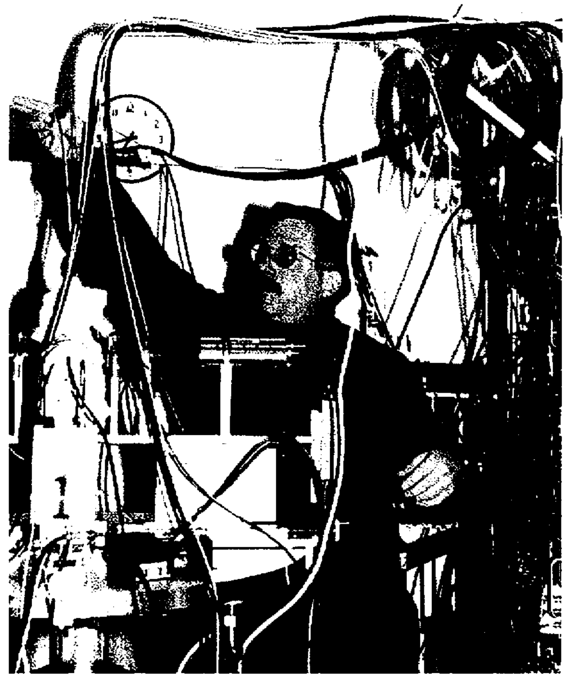

THE ANGULAR
CORRELATIONS
LABORATORY

# *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.

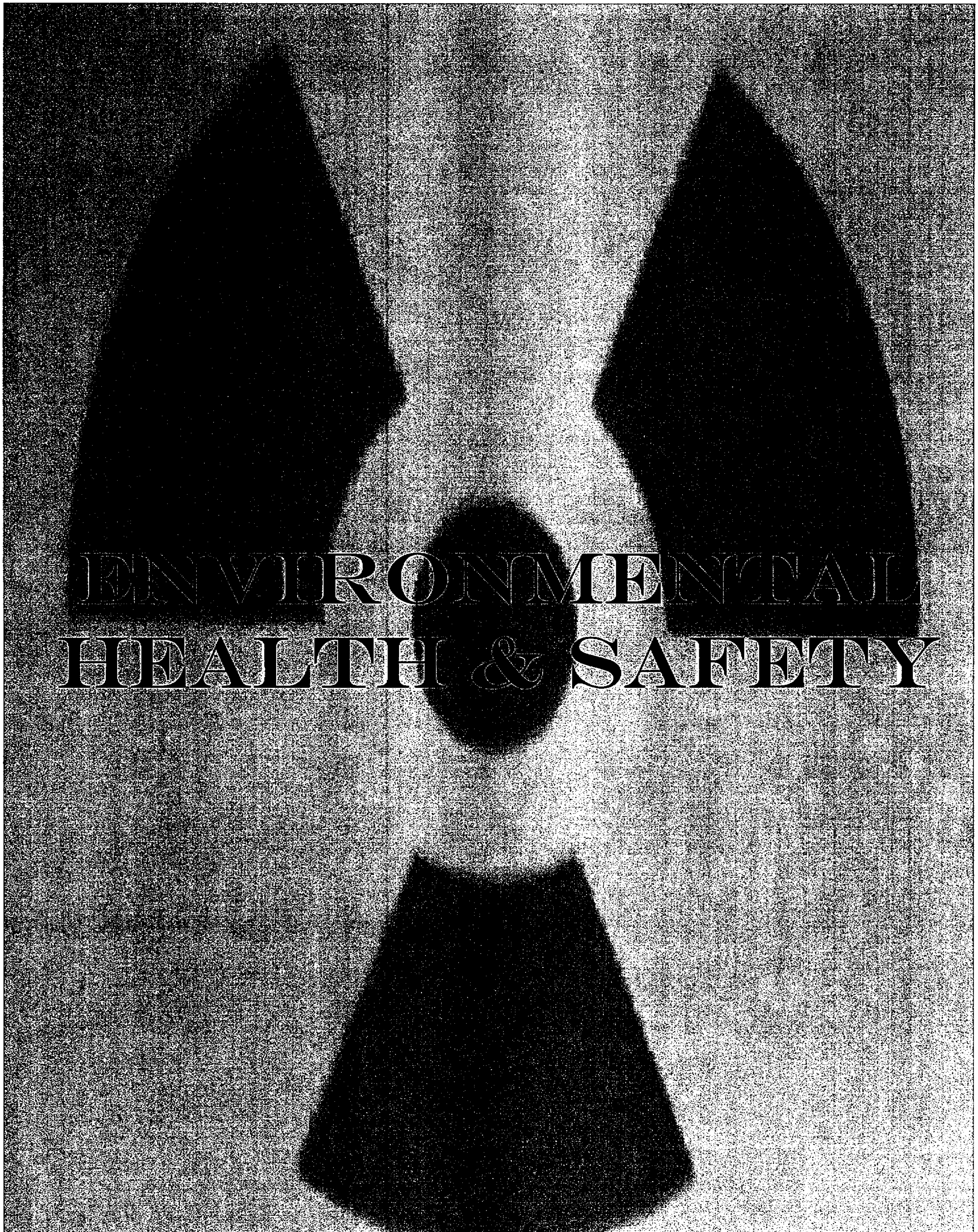


Prof. Catchen inserts a sample into a high-temperature sample furnace, which is mounted in the center of the four-detector array of the perturbed-angular-correlation spectrometer

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.


ENVIRONMENTAL
HEALTH & SAFETY

# IX. ENVIRONMENTAL HEALTH AND SAFETY

Environmental Health and Safety (EHS), with responsibility for ensuring the health and safety of employees, students and visitors to occupational and environmental hazards at Penn State, is an active participant in ensuing the overall safety of the Radiation Science and Engineering Center (RSEC) operations. Together, EHS and the RSEC staff implement a number of programs to ensure these responsibilities are met. 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 safely operate the Breazeale Nuclear Reactor at the Radiation Science and Engineering Center.

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. EHS and the RSEC collaborate to maintain the high level of health and safety programs necessary for compliance with federal and state regulations

Environmental Health and Safety 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 University is to keep radiation exposures as low as reasonably achievable (ALARA). This year, the EHS Radiation Protection Office (RPO) performed over 200 radiation surveys at the RSEC. The surveys were either contamination surveys to detect possible transferable contamination from radioactive materials work or radiation surveys of radiation sources such as activation products, sealed sources, equipment, and reactor operations. The 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. The surveys are redundant to the surveys performed routinely by the RSEC staff. The redundancy of the surveys is fundamental to the University s ALARA program.

Detailed radiation surveys were performed in the facility s Neutron Beam Laboratory (NBL) in support of commissioning the laboratory.

A radiation survey conducted in the RSEC s subcritical pile room located in a room adjoining the Aerospace Engineering s Wind Tunnel facility, Academic Projects Building (APB), indicated that levels of radiation could be further reduced in the Aerospace Engineering facility by relocating the fuel storage to an outside subterranean wall. EHS and RSEC personnel moved the fuel to the outside wall and transferred the radioactive neutron sources to the LINAC room, APB storage facility. The radiation levels in the Aerospace facility were reduced to background levels.

The EHS RPO staff provides representation at Monday and Wednesday morning RSEC status meetings. The meetings provide a forum for the participants to review the current reactor operations and experiments. This active participation has improved the communication between the RSEC and EHS.

Customer Service

The EHS RPO is responsible for the shipping and transfer of radioactive materials to customers other than the RSEC. The US Nuclear Regulatory Commission and the US Department of Transportation mandate complex requirements for the packaging, shipping and transfer of radioactive materials. The RPO facilitated twelve shipments for RSEC customers. Customer support in the packaging and shipping of Ar-41, Na-24, and Br-82 for Tru-Tec; Ar-41 and Br-82 for TracerCo; Na-24 for NWT Coporation; and Co-60 for Westinghouse was provided. The shipping and transfer of radioactive materials includes the disposal of reactor radioactive waste materials. This year the RPO shipped for disposal reactor hardware and experimental apparatus, including the activated $D_2O$ tank at a cost of $1,600, and the Bitteker experiment rig at a cost of $1,560.

An Industrial Hygiene Specialist performed a safety review of the design and construction of fixed ladder system in the facility. Appropriate recommendations were made to ensure safe operation of this system.

Licensing and Regulatory Requirements

Requirements for dosimetery are administered by the EHS RPO to measure staff, student, and worker radiation exposures. This year the RPO issued a total of 432 dosimeters to RSEC personnel. Administration of the dosimeter program includes issuing dosimeters, processing dosimeters and maintaining all dosimetery records. The RSEC's Director is provided with quarterly dosimeter reports for his review. There have been no doses this year that required investigation. Additionally, RPO provides on request, by signed permission only, dosimetry reports for reactor personnel and students so they can trace their exposure history. RPO provided 13 dosimetry reports to other nuclear facilities in order for them to maintain the individual s exposure profile. In August 1999, at the request of the RSEC, RPO initiated a thermal neutron dosimeter program to check exposures more accurately for those working around the NBL. One neutron dosimeter is a permanent fixture in the laboratory, and individuals wear the others as they work in the lab. A total of 132 thermal neutron dosimeters were monitored with no indication of 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. RPO has increased the auditing of these exposure records to catch administrative entry errors soon after they occur.

Eric Boeldt, Manager of Radiation Protection, is a member of the Penn State Reactor Safeguards Committee (PSRSC). During the past year, he initiated the presentation of a regular RPO report at each PSRSC meeting.

Chemical and fume hood ventilation checks were conducted to determine if airflow was within the established limits for proper ventilation by EHS. All nine fume hoods checked met the required occupational health standards.

Operational checks of the personnel emergency showers and eye wash stations were conducted throughout the facility. The facility's four emergency showers and three eyewash stations all met occupational health standards.

The EHS Supervisor of Laboratory Safety conducted a class on chemical safety for sixteen RSEC personnel. The Supervisor of Laboratory Safety worked with the RSEC to implement a chemical safety program, which incorporated changes to chemical waste management and chemical safety. The RSEC Facility Coordinator, Ken Rudy, was assigned responsibility for chemical safety at the facility. A walk-through of the reactor facility was conducted to review chemical and chemical waste storage practices. A chemical inventory throughout the facility was compiled to identify outdated and unused chemicals and approximately 1500 lbs. of chemicals were properly disposed of through a hazardous waste vendor.

<u>Training</u>

Training programs provided by EHS RPO to the RSEC are license and regulatory driven. This year, approximately twenty new reactor personnel and students attended the radiation safety orientation. Required retraining for all radiation workers was provided by means of a Newsletter distributed to all laboratory supervisors. EHS RPO conducted a training program for twelve of the RSEC s operational staff on the principals of ALARA and the use of Radiation Work Permits . A special training program was conducted for four 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 frequent customers.

At the request of the RSEC, the Fire Protection Engineer conducted a hands-on fire extinguisher training program for RSEC personnel. RSEC personnel had the opportunity to use different types of fire extinguishers and to experience their effectiveness in fighting fires using EHS's propane fueled fire simulator. Sixteen staff attended.

# RADIATION SCIENCE AND ENGINEERING CENTER RESEARCH AND SERVICE UTILIZATION

# X. 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 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 7 technical reports, presentations, or papers, 13 publications, 3 master's theses, and 1 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, 43 faculty and staff members, 26 graduate students and 16 undergraduate students have used the facility for research. This represents a usage by 13 departments or sections in 4 colleges of the University. In addition, 60 individuals from 24 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

## 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, significant changes occurred in the Native American cultures of the Mid-Atlantic and Northeastern regions of what is now the United States. These have been attributed to either a migration of southern people into the region or, alternatively, a transfer of traits from southern cultures. This study will attempt to clarify this issue.

One of the major cultural changes that occurred was the dramatically increased use of a lithic material called metarhyolite. Metarhyolite in the regions of study is limited to several widely-separated formations, one of which runs, roughly, along a north/south line through the Blue Ridge Mountains. We hypothesize that we should be able to differentiate between group migration and cultural diffusion in this setting.

Using the NAA capabilities of the Breazeale Nuclear Reactor facility, we intend to chemically characterize artifacts and geologic sources to match archaeological artifacts from dated sites to their sources of raw material. We expect to see a progression of source exploitation from south to north through time if a migration had occurred.

Greg Bondar manipulates samples

Currently, no quantitative examination of data has related to this issue. However, the significance of this research extends beyond the borders of this study area. One reason why this topic was selected was because it has the potential to discern an actual population migration based purely on the material culture of a prehistoric society. If successful, this method of analysis should prove useful to examine prehistoric migrations throughout the world.

So far, the results from five runs, of a total of 84 metarhyolitic samples, appear to demonstrate that suitable variation exists to permit the compositional discrimination of geologic formations, as well as some discrimination at the intraformational level. From these results, further results from two sites in the Virginia piedmont appear to confirm the hypothesis that materials from the Carolina Slate Belt were being transported into the Mid-Atlantic region 4,000 years ago, as shown in Figure 1.

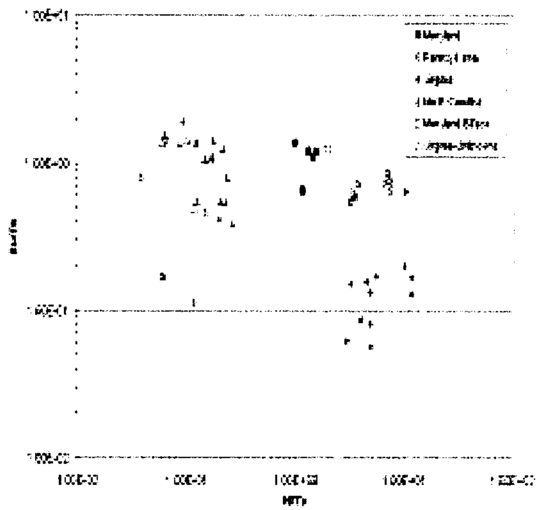
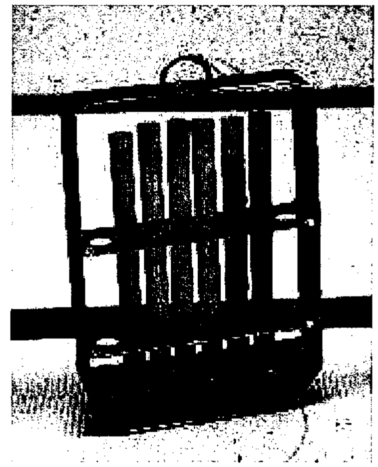


Figure 1: Plot of Eu/Tb ratios against Hf/Ta ratios demonstrating the association between artifact and source material.

These results were presented in February 2000, at the Upland Archaeology in the East Symposium #8 in Harrisonburg, Virginia in a paper titled “Lithics from the Uplands: The Characterization and Distribution of Eastern Metarhyolites”. Building on this enthusiastic reception, updated results were presented at the 65th Annual Society for American Archaeology meetings in Philadelphia, Pennsylvania in a symposium organized by the author. This paper was titled, “Prehistoric Distribution and Use of Metarhyolites in Eastern North America”. The results to date suggest that an additional ten runs of similar materials are needed to achieve statistically-significant conclusions. These additional runs will extend this research throughout the following year.

Session Planned:

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, Louisiana, 2001.



Sample Holder

Presentation Planned:

Bondar, G.H. Tracing the Transition: Examining Social Behaviour Through the Analysis of Lithic Artifacts. Paper to be presented at the Lithic Studies in the Year 2000 Symposium at the National Museum & Gallery in Cardiff, Wales, 2000.

Session Organized:

Bondar, G.H. and P. LaPorta. Lithic and Quarry Research along the Eastern Seaboard. Symposium at the 65th Annual Meeting of the Society for American Archaeology in Philadelphia, Pennsylvania, 2000.

Papers Presented:

Bondar, G.H. Prehistoric Distribution and Use of Metarhyolites in Eastern North America. Paper presented at the 65th Annual Meeting of the Society for American Archaeology in Philadelphia, Pennsylvania, 2000.

Bondar, G.H. Lithics from the Uplands: The Characterization and Distribution of Eastern Metarhyolites. Paper presented at the Upland Archaeology in the East

Symposium #8 in Harrisonburg, Virginia, 2000.

Bondar, G.H. A Preliminary Look at the Characterization and Distribution of Eastern Metarhyolites. Paper presented at the 1999, meetings of the Mid-Atlantic Archaeological Congress in Harrisburg, PA, 1999.

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.

## Chemistry Department

### POLYPHOSPHAZENE FUEL CELL MEMBRANES

Participants: M. Hofmann
E. Chalkova

Services Provided: Co-60 Irradiation and Crosslinking of Sulfonated Polyphosphazene Membranes for Fuel Cell Applications

## Nuclear Engineering

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

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

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

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 goals and is ready to proceed to the next phase. Four goals were defined for Phase 1 and are briefly discussed below.

**The first goal** was to upgrade the existing Experimental Changeable Reactivity Device (ECRD) and characterize its dynamics. (In the process of developing and approving the use of the new ECRD, it was determined that its name be changed from Secondary Control Rod as used in the proposal. The name change thus clearly distinguishes the ECRD from the control rods of the licensed monitoring, control and safety systems.) An ECRD is implemented as a TRIGA reactor moveable experiment where an aluminum tube containing an absorber material is positioned within the central thimble of the reactor by an experimental setup. With the completion of this goal, two ECRDs are now available for experimental monitoring and controls research. The reactivity worth of the original ECRD (ECRD #1) is approximately $0.35 and the reactivity worth of the newly constructed ECRD (ECRD #2) is approximately $0.94. ECRD #1 is used in experiments at power (up to 65%) where temperature changes produce significant reactivity changes. ECRD #2 was constructed for use at low power (less than 0.1%) where temperature change and its reactivity effect are negligible. The development of ECRD #2, which operates much more closely to the TRIGA reactor technical specification, was not a trivial exercise. The reactor facility staff performed a safety analysis, which was reviewed by the Penn State Reactor Safeguards Advisory committee. The reactor staff constructed the device and developed and executed the procedures to initially characterize its dynamics. ECRD #2 is worth approximately $0.94 reactivity and can be moved the length of its travel in approximately 3.5 seconds. An experimental worth curve shows that the ECRDs' differential worth is highest with approximately three-quarters inserted where the control rods do not shadow it.

**The second goal** was to convert an existing Hybrid Reactor Simulation (HRS) capability using MATLAB real-time workshop to Windows NT platform. A HRS is implemented when a real-time simulation of BWR reactivity dynamics positions an ECRD and causes the TRIGA-reactor observed power response to mimic stability phenomena actually encountered in BWRs. Hybrid simulation in this context refers to the use of the research reactor time response as an analog solution to the neutron kinetics equations. The TRIGA reactor's solution for the power response is used as an input signal to a real-time digital simulation of power-reactor thermal-hydraulics, which in-turn provides a reactivity feedback signal to the TRIGA through positioning of an ECRD. Figure 1 presents a top-level display of a HRS implemented in the current environment. The input signal to the block labeled ECRD+TRIGA is a reactivity rate signal in cents/second. A voltage signal is computed within the block and sent to the ECRD motor drive where it is processed as a velocity command. The reactor power output signal of the block is obtained by digitizing a voltage

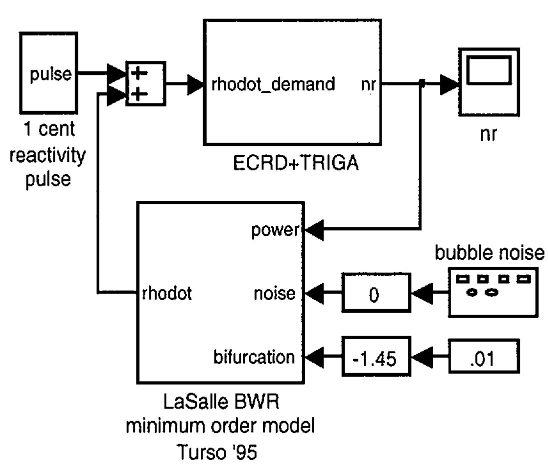



Fig 1: SSIMULINK model of BWR Reactivity Feedback

from a micro-micro ammeter driven by a CIC. All input and output signals used by the experimenter are independent and isolated from the licensed digital control and analog safety system.

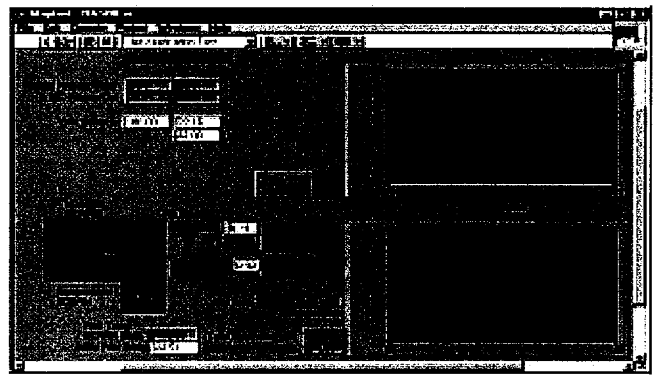


**Figure 2: Hybrid Testloop Simulation (HLS) LabView Interface**
Note: This particular screen was generated offline with the loop shutdown, without power applied to the rods and thus without significant reactivity feedback.

The previously developed HRS used a now obsolete UNIX-network microprocessor-based control system. The conversion to the PC platform was needed to obtain currently available high performance computing to achieve real-time performance of high fidelity boiling channel simulations, as well as better supported application software. A Pentium 550 MHz and an AMD 1000 GHz PC computer were obtained and can be operated in two configurations for experiments. A National Instruments data acquisition card is installed in the AMD computer. It can be operated in a stand-alone mode where the graphical user interface and real-time application operate on the same computer using the MATLAB real-time workshop windows real-time target option. The second mode uses the MATLAB xPC real-time target option where a special real-time operating system is loaded on the AMD and it communicates with a windows-based graphical user interface on the Pentium computer. As more sophisticated graphical information displays are developed in Phase 2, it is anticipated that the second mode with both computers will be essential to maintain real-time performance while generating more sophisticated real-time graphics.

In addition to converting the previous HRS simulation, other important HRS experiments involving optimal control, robust control, and optimized feed-forward control were also readily converted to the PC platform.

**The third goal** was to develop real-time detailed simulation of commercial BWR boiling channels and modal kinetics in the HRS. Ceceñas-Falcón's boiling channel model, described in Reference 1, was converted to the real-time execution requirements of the MATLAB real-time workshop. This conversion required extensive revision of MATLAB m-file programming to required SIMULINK C-mex S-function programming. The converted model can now be readily incorporated in HRS simulation. A block representing a detailed boiling channel model simply replaces the block labeled "minimum order model" in Figure 1. The boiling channel models for Vermont Yankee and LaSalle utilize 20 axial nodes to implement nonlinear first-principles conservation of mass, momentum, and energy equations. The model makes extensive use of water and steam properties tables and is thus computationally intensive. Nonetheless, the model's real-time performance on the AMD 1000 GHz computer is excellent and readily allows the simulation of two (or more) boiling channels for hybrid reactor simulation of BWR out-of-phase oscillations. Out-of-phase BWR behavior is implemented in the HRS by using the TRIGA reactor to obtain an analog solution of the in-phase (or fundamental mode) dynamics while the out-of-phase (or first-harmonic mode) amplitude is simulated. The coupling of the simulated out-of-phase mode to the TRIGA generated in-phase mode is achieved by appropriately modifying the reactivity rate signal to the ECRD. Simulated void reactivity feedback paths are provided for each of the fundamental and first-harmonic modes.

**The fourth goal** was to develop an initial hybrid testloop simulation (HLS) to utilize simulation of point kinetics interfaced to the HLS heater rods. The Penn State thermal-hydraulic test loop mimics the boiling phenomena of a Simplified Boiling Water Reactor (SBWR), an advanced reactor design concept, in a unique atmospheric pressure facility where flow visualization is afforded by borosilicate glass piping. Electrically heated rods take the place of the nuclear reactor fuel. The design and construction of the test loop has been a multiyear undergraduate design project that is entering an operational phase with manual or open-loop control of the electrically heated rods.

The initial HLS was implemented using the existing test loop computer and data acquisition system, a 250 MHz Pentium computer. The test loop computer uses data-acquisition cards from Computer Boards Inc, which are not all currently supported for use with the MATLAB real-time workshop. The initial HLS was implemented with National Instruments LabView software. LabView provides extensive graphical interface development tools and includes the capability to create a virtual interface for world-wide-web based experiments. Some work in a separate DOE reactor-sharing project at Penn State has already demonstrated the LabView web-based interface to an undergraduate reactor oscillator experiment. An effort to extend the HLS operation to the web was not identified as a goal of the proposal, but it will be pursued provided that it does not interfere with achieving Phase 2 goals or provided that alternate funding can be obtained. An example of using LabView for web-based virtual experiments that we look to can be found at http://vll.phys.dal.ca/.

Although LabView provides a rich operator interface environment, it does not appear to presently offer MATLAB's ease of implementing complex real-time computationally intensive simulations, such as a boiling channel. (The LabView interface for the initial HLS is shown in Figure 2.) Conversely, MATLAB provides a rich environment for implementing real-time computationally intensive simulations but does not appear to offer LabView's ease of implementing a sophisticated operator interface. Phase 2 work will seek a solution for obtaining both computationally intensive real-time hybrid simulations with a good operator interface.

In the initial LabView-based HLS, measurements of void fraction and temperature from thermocouples embedded in the heater rods provided feedback signals to adjust reactivity of a simulated reactor kinetics response. The simulated reactor kinetics response was then used to set the electrical power delivered to the heater rods. A simulated control rod position is provided for manual control of the HLS in an analogous manner as a reactor. As the operator moves the simulated control rod, the physical fuel-temperature and void measurements generate simulated reactivity feedback to bring the HLS to new stable power levels. Some interesting opportunities for additional research to enhance the HLS include distributed-parameter estimation of void distribution along the length of the fuel bundle and processing of the temperature measurements to identify and filter the effects of spurious or failed thermocouple readings. Distributed-parameter estimation of void-fraction distribution would benefit from the development and validation of a first-principles (or experimentally determined) boiling channel model of the test loop, which is also needed in the Phase 3 effort to implement an out-of-phase HLS.

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 goals and is ready to proceed to the next phase. Phase 2 is scheduled to run from July 1, 2000 to December 31, 2000. The Phase 2 goals are 1) to evaluate on-line uncertainty monitoring for robust control validation, and 2) to develop enhanced information displays to convey real-time information of HRS with out-of-phase stability characteristics.

Publications:

The following eight forthcoming publications will further elaborate on this work:


1. Ceceñas-Falcón, M., and R.M. Edwards. "Stability Monitoring Tests Using a Nuclear-Coupled Boiling Channel," to appear in <u>Nuclear Technology</u> (July 2000).

2. Edwards, R.M. "Expansion of a Testbed for Advanced Reactor Monitoring and Control," <u>Trans. Amer. Nucl. Soc.</u> <u>82:</u>, San Diego, CA, (June 4-8, 2000).


The following papers are under final preparation for publication in the proceedings of <u>The Third American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies,</u> NPIC&HMIT 2000, Washington D.C., November 12-16, 2000. (It is expected that they will evolve into journal publications in the coming year.)


3. Ceceñas-Falcón, M., and R.M. Edwards. Out-of-Phase BWR Stability Monitoring.

4. Shyu, S., and R.M. Edwards. Optimized-Feedforward and Robust-Feedback Used in Integrated Automatic Reactor Control.

5. He, W., Z. Huang and R.M. Edwards. Experimental Validation of Optimized-Feedforward Control for Nuclear Reactors.

6. Huang, Z., and R.M. Edwards. High-fidelity Hybrid Reactor Simulation of BWR.

7. Shaffer, R., and R.M. Edwards. Experimental Validation of Robust Control for Nuclear Reactors.

8. Edwards, R.M. Integration of a Thermal-Hydraulic Test-loop and University Research Reactor for Advanced Monitoring and Control Research.



Sponsor: Department of Energy

## INTERACTIVE EXPERIMENTS OVER THE INTERNET

Participants: R. M. Edwards
R. Erhardt

Services Provided: Reactor and Operations Support Staff, Auxiliary Instrumentation, and Electronics Shop

The objective is to use emerging software capabilities in National Instruments Labview Software to provide an interactive internet-based interface to research reactor experiments such as those conducted in the long-standing undergraduate laboratory on reactor experiments, NucE 451. It is believed that such a capability can enable Nuclear Engineering students at institutions without a research reactor to include an experimental component in their studies. More broadly, it may be possible to design interactive activities and experiments that can appeal to high school science classes and the general public and thus contribute to improving understanding and acceptance of nuclear processes.

Thus far, an elementary version of the NucE 451 oscillator experiment has been demonstrated with internet broadcast of real-time data acquisition to multiple end users on the web. Current work is expanding the interface to include remote interaction to control data acquisition parameters and starting and stopping of data acquisition. A video camera and web-streaming video capture card are being added to provide a real-time video interface between a remote and local experimenter and reactor operators. In addition, the possibility of enabling a remote experimenter to control physical characteristics of the experimental apparatus, such as oscillator speed and resultant frequency of reactivity fluctuations, is under consideration.

Sponsor: DOE, Reactor Sharing Program, 1999-2000.

## NE 451, UNDERGRADUATE LABORATORY OF REACTOR EXPERIMENTS

Participants: R. M. Edwards
J. S. Brenizer
M. E. Bryan
T. L. Flinchbaugh

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. Each weekly laboratory exercise usually consists of two lectures and one laboratory session. The first course (NucE 450) covers radiation instrumentation and measurement and is conducted in the 2nd semester of the junior year. By the beginning of the senior year, the students have already covered the LaMarsh Introduction to Nuclear Engineering text including reactor point kinetics. The 451 course then emphasizes experiments using the instrumentation that was covered in the first course and is divided into two (more or less) equal "tracks". These tracks can be coarsely described as TRIGA and non-TRIGA experiments and each is the major responsibility of a different professor. The non-TRIGA track includes three graphite pile, two analog simulation, and one power plant measurement experiments. In 1999, 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.

## POINT DEFECTS IN Zr-Fe INTERMETALLIC COMPOUNDS STUDIED USING PERTURBED-ANGULAR-CORRELATION SPECTROSCOPY

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

Services Provided: Angular Correlations Lab, Laboratory Space, and Machine Shop

We have measured the temperature dependencies of the electric and magnetic hyperfine interactions at $^{181}$Ta nuclei substituted into the Zr site in the Laves-phase compound $Fe_2Zr$, using the perturbed angular correlation of $\gamma$-rays emitted after the $\beta^-$decays of $^{181}$Hf probe nuclei. Although the overall crystal structure is cubic, a weak strongly-damped electric-quadrupole interaction is observed, which shows no significant temperature dependence over the investigated temperature range from 290K to 1300K. Thus, below the magnetic ordering temperature $T_C$ of 631(2)K, we observe combined magnetic-dipole and electric-quadrupole hyperfine interactions. Two separate magnetic components characterize the magnetic-dipole interactions. For the interaction at the primary site, which is occupied by 70-80% of the probes, the Larmor frequency measured at laboratory temperature has a value of $\omega_L$ = 407(1)MRad sec$^{-1}$. The secondary site is populated by the remaining 20-30% of the probes, for which the corresponding Larmor frequency has a 290K value of $\omega_L(0)$ = 579(3)MRad sec$^{-1}$. We attribute the primary interaction to the "perfect-crystal" probe environment at the Zr site, whereas we ascribe the secondary interaction to the enhancement of the transferred hyperfine field by the presence of Fe anti-site defects near the Zr site. At temperatures below but very close to $T_C$, those frequencies cannot be determined for either interaction, because the magnetic-hyperfine and the electric-quadrupole frequencies converge to comparable values and electron-spin disordering produces increased line broadening. We have now been investigating the compounds $Zr_3Fe$ and $Zr(Fe,V)_2$.

Publications:

Motta, A.T., S.E. Cumblidge, G.L. Catchen, R.L. Rasera, A. Paesano, Jr., and L. Amaral. Defects and Magnetic Hyperfine Fields in $ZrFe_2$ Studied Using Perturbed Angular Correlation Spectroscopy, Physical Review B, 60(2), pgs. 1188-1196. 1999.

Motta, A.T., S.E. Cumblidge, G.L. Catchen, L. Amaral, and A. Paesano, Jr. Investigating Crystal and Magnetic Hyperfine Fields in $Zr_3Fe$ and $ZrFe_2$ Using PAC Spectroscopy. XXI International Meeting on Condensed Matter Physics, Caxambu, Brazil. 1998.

Cumblidge, S.E., A.T. Motta, G.L. Catchen, L. Amaral, A. Paesano, Jr., and R.L. Rasera. Temperature Dependence of Magnetic Hyperfine Fields at $^{181}Ta$ in $ZrFe_2$. 11th International Conference on Hyperfine Interactions. Durban, South Africa. 1998.

Cumblidge, S.E., G.L. Catchen, A.T. Motta, S.B. Legoas, and L. Amaral. Investigating Hyperfine Fields in Zr3Fe Using Perturbed Angular Correlation Spectroscopy. To be submitted to Physical Rev. B. 1999.

Sponsors: National Science Foundation Grant number INT-9503934, and support from the Brazilian National Research Council (CNPq).

## VARIOUS ANALYSES OF SAMPLES USING THE SERVICES OF THE RADIONUCLEAR APPLICATIONS LABORATORY

Participant: T. H. Daubenspeck

Services Provided: Neutron Irradiation, Neutron Activation Analyses, Radiation Counters, Flux Monitoring, and Shielding Design

Twenty (20) radioisotope production runs were performed during the past year. A total of 1.25 curies of Bromine-82 (four runs), 1.0 curie of Sodium-24 (1 run), and 1.625 curies of Argon-41 (2 runs) were produced for Tru-Tec (Flenniken, Kolek). A total of 3,915 curies of Sodium-24 (9 runs) were produced for NWT Corporation (Palino). A total of 3.0 curies of Sodium-24 (1 run) and 0.9 curies of Argon-41 (3 runs) were produced for Synetix (Boone, Gaudin).

A total of 546 semiconductor inrradiations were performed during the past year. Intersil Corporation (formerly Harris Semiconductor)–419, TRW Inc.–73, Raytheon Company–37, and Raytheon/ E-Systems–6, Raytheon Systems Company (formerly Hughes Aircraft)–10, and Honeywell–1.

Irradiation and analyses of obsidian and rhyolite samples. (Anthropology: Greg Bondar)

NAA demos for high school, college, and miscellaneous tours. (RSEC: Davison)

Flux distribution study work for Fast Neutron Irradiator (FNI) using thermal and fast neutron monitoring foils. (MN&E: Dr. Bojan Petrovic)

Pottery sample irradiation and analyses for high school science fair project. (Ephrata H.S.: Courtney Boehme)

**COMPTON SCATTER GAUGE**

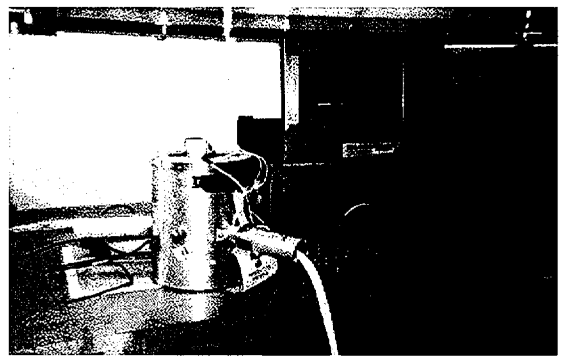
Participants: E. H. Klevans
E. S. Kenney
W. He
S. Li
S. Lobdell
R. Ulrich
V. E. Whisker
B. L. Wilks
M. E. Bryan
B. J. Heidrich
R. L. Eaken
J. Armstrong
M. P. Grieb

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. 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 new detector unit was purchased and showed stable performance,

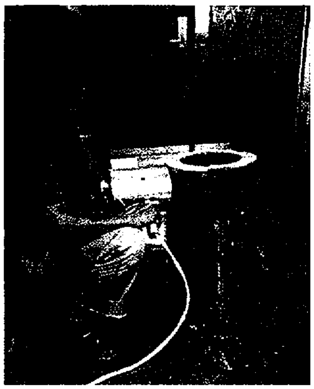
Assembly of the Compton Scatter Gauge

in contrast to the units in use last year. Detailed studies of statistical and system uncertainties in the measurements are in progress. Field tests were conducted at the Dresden Nuclear Station in October 1999, on two feedwater heaters. Significant errors in measurement occurred because of insulation thickness departing significantly from the nominal thickness, giving the appearance of wall thinning when no such thinning had occurred. This lead to the development of a new class of collimators, called "broad focus collimators", that produce little count rate change over +/- 0.25" change in insulation thickness. These were initially evaluated and developed using a Monte Carlo code and have been built and successfully tested for empty pipes. A different solution to insulation thickness variation is needed for water-filled pipes,



Compton Scatter Gauge with computer that converts count rate to thickness

and this is under intense investigation. Two new methods for independently determining insulation thickness have been devised and tested. Studies have also shown that for water-filled pipes there is an important count rate dependence on insulation density. A method for approximately determining insulation density has been devised. New tests for water-filled pipes are planned for September at the EPRI testing center. Progress has also been achieved on three additional topics. A source analysis using a Monte Carlo model has shown that the amount of HgO in the source can be reduced by 75% without a loss in gamma ray output. This will be tested in the coming year. A second study has produced an analytical code to design collimators to supplement the Monte Carlo model. It was initially developed for a "pencil beam" model but has been extended to include a finite beam. Finally, a three dimensional heat conduction model is being developed for the sources during neutron irradiation to see if more than one source could be produced at a time.



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

Master's Theses:

Whisker, V., E.H. Klevans and E.S. Kenney (co-advisers). Design Optimization and Field Testing of the Compton Scatter Gauge. December 1999.

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

Li, S., E.H. Klevans and E.S. Kenney (co-advisers). Methods to Deal with Insulation Thickness Variation in the Field. In progress.

Publication:

Klevans, E.H., E.S. Kenney, R.L. Baxter, K.A. Burkert, B. Petrovic, B. Wilks, and W.J. Groszko. An Erosion-Corrosion Monitor Using Gamma Ray Backscatter. Proceedings of the EPRI Fifth Piping and Bolting Conference. June 25, 1999.

Sponsors: Commonwealth Edison Company $500,000
Exxon Research Corporation $53,000

**QUALIFICATION TESTING OF NEUTRON ABSORBER MATERIAL**

Participants: K. Lindquist
D. Vonada

Services Provided: Electronics Shop, Laboratory Space, Machine Shop, Neutron Radiography and Neutron Transmission

A boron carbide aluminum composite material is being qualified for use in spent nuclear fuel storage racks and dry storage casks. This material is used to maintain the fuel storage array in a subcritical condition. Elevated temperature testing, accelerated corrosion testing and irradiation testing is being completed. After exposing coupons of this material to accelerated service conditions, the physical properties of this material are evaluated.

Sponsor: Reynolds Metal Company

**POST IRRADIATION INSPECTION AND TESTING OF NEUTRON ABSORBER MATERIALS**

Participants: D. Kline
D. Vonada
K. Lindquist

Services Provided: Electronics Shop, Laboratory Space, Machine Shop, Neutron Radiography and Neutron Transmission

The purpose of this work is to quantitatively characterize the in-service physical properties of neutron absorber materials used in spent fuel storage racks and shipping casks. Utilities use surveillance coupons of neutron absorber materials such as Boraflex, BORAL, borated graphite and NEUTRASORB borated stainless steel to track the performance of these materials in casks and racks. The coupons are tested with respect to dimensional changes, weight changes, hardness changes, density changes, changes in dynamic shear modulus and neutron attenuation characteristics. The latter measurements are performed in the Neutron Beam Laboratory.

Sponsor: Various Electric Utilities

## 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 and 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.

## EVALUATING TWO PHASE FLOW USING NEUTRON RADIOGRAPHY

Participants: M. E. Bryan
D. E. Hughes
J. H. Murphy
M. A. El-Ganayni

Services Provided: Neutron Radiography, Machine Shop and Electronics Shop

This project is using neutron radiography to observe 2-phase fluid flow experiments. An upgraded flow loop was built, and flow measurements at pressures up to 2000 psi are ongoing. A second project studied reflood in a hot channel at atmospheric pressure using the techniques developed for this work. Several other heat pipe test sections are also being studied.

Sponsor: Bettis Atomic Power Laboratory $70,436

### NUCE 450, RADIATION DETECTION AND MEASUREMENT

Participants: W. A. Jester
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.

## Physics Department

### COLD CATHODE SOURCE

Participants: A. Badzian
B. Weiss
L. Pilione

Service Provided: Gamma Irradiation

The electron emission properties of diamond thin film appear to have a dependency on the atomic disorder of the diamond lattice. Synthetic diamond samples prepared at the Materials Research Laboratory (PSU), have indicated that by selectively changing the microwave chemical vaporization deposition conditions of diamond growth, the atomic disorder and the subsequent electron emission properties increase. Exposing several of these samples to the gamma rays of the cobalt-60 source at the Breazeale Reactor facility created damage sites similar to those produced during the film deposition. The irradiation experiments were conducted on a suite of samples whose electronic emission properties have previously been determined. The emission results ranged from sample to sample from poor to good. Post irradiation emission results were evaluated as to the effect of gamma induced damage.

# 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 |
| Commonwealth Edison Company | Compton Scatter Gauge Development |
| David Sarnoff Labs | Semiconductor Irradiation |
| Eagle-Picher | Neutron Radiography<br>Neutron Radioscopy<br>Neutron Transmission |
| Exxon Research Corporation | Compton Scatter Gauge Development |
| Harris Semiconductor | Semiconductor Irradiation |
| Honeywell | Irradiation of Electronic Devices |
| Industrial Quality | Neutron Radiography |
| Intersil Corporation (formerly Harris Semiconductor) | Semiconductor Irradiation |
| Lockheed Martin | Semiconductor Irradiation |
| Materials Engineering Association (MEA) | Hot Cell Use |
| NETCO (Northeast Technology Corporation) | Neutron Radioscopy<br>Neutron Transmission |
| Nuclear Research Corporation | Isotope Production |
| NWT Corporation | Isotope Production<br>Shielding Study |
| Oglevee Ltd. | Gamma Irradiation |
| Raytheon Company / E-Systems, St. Petersburg, FL | Irradiation of Electronic Devices |
| Raytheon Company, Sudbury, MA | Irradiation of Electronic Devices |
| Raytheon Systems Company, El Sequndo, CA | Irradiation of Electronic Devices |
| Reynolds Metals | Neutron Radiography<br>Neutron Transmission<br>X-Ray |
| Royal Military College of Canada | Neutron Radiography<br>Neutron Radioscopy |
| SYNETIX (formerly Tracerco) | Isotope Production |
| Transnucleaire, France | Neutron Radiography<br>Neutron Radioscopy<br>Neutron Transmission |
| Transnuclear, New York | Neutron Radiography<br>Neutron Radioscopy<br>Neutron Transmission |
| Tru-Tec | Isotope Production |
| TRW | Semiconductor Irradiation |
| University of Maryland | Perturbed Angular Correlation |

# APPENDICES

## *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 | |
|---|---|
| **Agronomy:** | |
| Amistadi, Mary | S |
| Dail, Bryan | F |
| **Dairy/Animal Science:** | |
| Henning, William | F |
| **Horticulture:** | |
| Brothers, Kevin | U |
| Graig, Richard | F |
| **Plant Pathology:** | |
| Juba, Jean | S |
| **Veterinary Science:** | |
| Panek, Leigh | S |
| Pircher, Tony | G |
| Wojchowski, Don | F |
| Zhao, Shuging | 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 SCIENCE | |
|---|---|
| **Biology:** | |
| Lai, Zhi-Chun | F |
| Nguyen, Duc | PD |
| **Chemistry:** | |
| Allcock, Harry | F |
| Cannon, A | G |
| Chalkova, Elena | G |
| Hofmann, M | G |
| Maher, Andrew | G |
| Morford, R | G |
| Prange, Robin | G |
| Taylor, Jonathan | G |
| **Physics:** | |
| Badzian, A | F |
| Pilione, L | FE |
| Weiss, B | PD |

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

| COLLEGE OF ENGINEERING | |
|---|---|
| **Nuclear Engineering:** | |
| Armstrong, Jeff | S |
| Baratta, Anthony | F |
| Baxter, Robert | G |
| Bilovsky, Vincent | G |
| Brenizer, Jack | F |
| Bryan, Mac | S |
| Burkert, Kevin | G |
| Buschman, Francis | U |
| Carlin, Erin | U |
| Catchen, Gary | F |
| Cawley, Scott | U |
| Cecenas-Falcon, M | G |
| Cumblidge, Stephen | G |
| Daubenspeck, Thierry | S |
| Davison, Candace | S |
| Eaken, Ronald | S |
| Edwards, Robert | F |
| Erhard, Richard | U |
| Flinchbaugh, Terry | S |
| Grider, Mark | U |
| Grieb, Mark | S |
| Groszko, W | G |
| Haghighat, Alireza | F |
| Hahn, Diana | U |
| Hanna, Shane | U |
| He, Weidong | G |
| Heidrich, Brenden | G |
| Helton, Alison | S |
| Hochreiter, Larry | F |
| Huang, Zhengzyu | G |
| Hughes, Daniel | F |
| Jester, William | F |
| Kenney, Edward | FE |
| Klevans, Edward | FE |
| Kohlepp, Kaydee | U |
| Lebiedzik, Jana | S |
| Levine, Samuel | FE |
| Link, Travis | U |
| Lobdell, Simon | U |
| Morlang, Michael | S |
| Motta, Arthur | F |
| Nixon, Wayne | U |
| Petrovic, Bojan | F |

| COLLEGE OF ENGINEERING | |
|---|---|
| **Nuclear Engineering(cont.):** | |
| Plum, Ryan | U |
| Rankin, Paul | S |
| Rasera, Rob | VP |
| Rudy, Kenneth | S |
| Schaeffer, Roman | G |
| Sears, C. Frederick | F |
| Shyu, S | G |
| Simonetti, Travis | U |
| Sridharan, Arunkumar | G |
| Sullivan, Joe | U |
| Ulrich, R | G |
| Werkheiser, Dave | S/U |
| Whisker, Vaughn | G |
| Wilks, Ben | G |
| Williams, Monica | G |
| Witzig, Warren | FE |

| MATERIALS RESEARCH LABORATORY | |
|---|---|
| Dougherty, Joseph | F |

| ENGINEERING SCIENCE AND MECHANICS | |
|---|---|
| Lenahan, P | F |
| Mishener, Tetsuya | G |

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

# APPENDIX A

| INDUSTRIES, ETC. | |
|---|---|
| Bettis Labs, Westinghouse | Dennis Angel<br>Lawrence Blondsley<br>Dave Chauvet<br>John Dumbar<br>M. A. El-Ganayni<br>Larry Fore<br>Jack Murphy<br>Joe Saccio<br>John Snyder |
| David Sarnoff Labs | Ronald Smeltzer |
| Eagle-Picher | Monte Hart<br>Dennis Manning<br>Marvin Wachs |
| Honeywell | Dennis Collins |
| Intersil Corporation, Mountaintop, PA | Frank Kalkbrenner<br>Joe Macieunas |
| Intersil Corporation, Findlay, OH | Frank Lau |
| Industrial Quality | Harry Berger |
| Lockheed-Martin | Robert Gigliuto |
| Materials Engineering Associates | Frank Loss<br>Bob Taylor |
| Northeast Technology Corporation | Matt Harris<br>Ken Lindquist<br>Doug Vonada |
| NWT Corporation | G. F. Palino |
| Oglevee, Ltd. | Vincent Grossi |
| Philadelphia Electric Company | Earl Abbott<br>Mark Brisan |
| Raytheon | Geoffrey Casteel<br>Guido Enriquez<br>George Gong<br>Robert Johnson<br>Tien Lang<br>Chris Mikulski<br>Stewart Mulford<br>Donald Stransky |
| Raytheon Company E-Systems | Ed Craig |
| Raytheon Systems Company | Craig Uber |
| Reynolds Metals | Joel Archibald<br>Thomas Chadwick<br>Robert Kazmier |
| Royal Military College of Canada | Les Bennett<br>Bill Lewis |

# *APPENDIX A*

| INDUSTRIES, ETC. | |
|---|---|
| Synetix (Formerly Tracerco) | Mike Boone<br>Dave Bucior<br>Roy Dobson<br>Dan Gaudin |
| Transnuclear, New York | William Bracy<br>Richard Flinn<br>Glenn Guerra<br>Bill Sutherland |
| Transnucleaire, France | Gilles Bonnet<br>Rene Chiocca<br>Franck Martin<br>Philippe Naigeon |
| Tru-Tec | Mike Flenniken |
| TRW | Frank Cornell<br>Russ Graham<br>Terry Lunn<br>Don Randall |
| University of Maryland | Robert Rasera |

# *APPENDIX B*

## FORMAL TOUR GROUPS

| Group Name | Date | # Visitors |
|---|---|---|
| Museum Exhibits Tour | 07/01/99 | 1 |
| Prospective NucE Students Tour | 07/01/99 | 2 |
| TRAC Users Group Tour | 07/01/99 | 2 |
| PGSAS Tour | 07/06/99 | 34 |
| Sanders Family Tour | 07/07/99 | 4 |
| Employee Relations/Human Resources Tour | 07/07/99 | 2 |
| Lawrence Livermore Labs Tour | 07/08/99 | 1 |
| Glickstein Family Tour | 07/08/99 | 2 |
| PGSAS Tour | 07/08/99 | 34 |
| Agricultural Engineering Faculty Tour | 07/09/99 | 1 |
| Prospective Graduate Student Tour | 07/09/99 | 1 |
| Holderman-Personal Tour | 07/09/99 | 1 |
| Vendors | 07/13/99 | 3 |
| PREF Tour | 07/13/99 | 18 |
| OPP Tour | 07/13/99 | 1 |
| Upward Bound Career Tour | 07/13/99 | 2 |
| Rosemount Tour | 07/13/99 | 1 |
| Smith Family Tour | 07/14/99 | 2 |
| Ritenour Staff Tour | 07/14/99 | 1 |
| Gamma Irradiation Demo | 07/14/99 | 1 |
| View Tour | 07/15/99 | 17 |
| Bettis Tour | 07/15/99 | 1 |
| Koper-Personal Tour | 07/15/99 | 1 |
| McGrath-Personal Tour | 07/15/99 | 1 |
| Alumni Vacation Student's Tour | 07/15/99 | 14 |
| Upward Bound Math/Science Tour | 07/15/99 | 18 |
| McCartney's Tour | 07/16/99 | 1 |
| Sear/Brown Tour | 07/16/99 | 1 |
| WISE Program Tour | 07/19/99 | 14 |
| Forbes Family Tour | 07/19/99 | 2 |
| PSU Graduate Students Tour | 07/19/99 | 2 |
| PGSAS Tour | 07/19/99 | 19 |
| Girl Scout Camp | 07/19/99 | 55 |
| WISE Program Tour | 07/20/99 | 15 |

| Group Name | Date | # Visitors |
|---|---|---|
| Carlin-Personal Tour | 07/21/99 | 1 |
| BEST Tour | 07/21/99 | 25 |
| View Tour | 07/22/99 | 13 |
| Dildine Family Tour | 07/22/99 | 4 |
| Juniata Valley (Summer Program) Tour | 07/22/99 | 57 |
| PGSAS Tour | 07/22/99 | 19 |
| PSU Students Tour | 07/23/99 | 2 |
| Alumni Tour | 07/23/99 | 2 |
| PGSAS Tour | 07/23/99 | 19 |
| Spend a Summer Day Tour | 07/23/99 | 16 |
| PGSAS Tour | 07/26/99 | 19 |
| Spend a Summer Day Tour | 07/26/99 | 6 |
| PGSAS Tour | 07/27/99 | 19 |
| ARL/NRC Tour | 07/27/99 | 4 |
| OPP Tour | 07/28/99 | 3 |
| PGSAS Tour | 07/28/99 | 19 |
| Nuclear Science Teachers Course | 07/28/99 | 15 |
| NucE 505 | 07/29/99 | 2 |
| Porter-Personal Tour | 07/30/99 | 1 |
| Bettis Tour | 07/30/99 | 3 |
| Spend A Summer Day Tour | 07/30/99 | 14 |
| OPP Tour | 08/02/99 | 2 |
| Spend a Summer Day Tour | 08/02/99 | 4 |
| Executive Management Program Tour | 08/02/99 | 1 |
| Executive Management Program Tour | 08/02/99 | 1 |
| Tru-Tech Tour | 08/03/99 | 1 |
| View Tour | 08/05/99 | 15 |
| Radiation Protection-Personal Tour | 08/06/99 | 1 |
| Reilly-Personal Tour | 08/06/99 | 1 |
| Andes Family Tour | 08/06/99 | 5 |
| Weigle-Personal Tour | 08/09/99 | 1 |
| IPAC Tour | 08/12/99 | 1 |
| Jan A- Personal Tour | 08/13/99 | 1 |
| McCartney's Tour | 08/16/99 | 2 |

# *APPENDIX B*

## FORMAL TOUR GROUPS

| Group Name | Date | # Visitors |
|---|---|---|
| Keenan-Personal Tour | 08/16/99 | 1 |
| Mary Kay-Personal Tour | 08/19/99 | 3 |
| PSU Faculty Tour | 08/20/99 | 1 |
| PSU Student Tour | 08/23/99 | 2 |
| Chemical Engineering Tour | 08/23/99 | 1 |
| OPP Pump Meeting | 08/24/99 | 3 |
| OPP Tour | 08/25/99 | 1 |
| Bryce Jordan Center Athletic Dept. Tour | 08/25/99 | 1 |
| Yellow Freight Tour | 08/27/99 | 1 |
| Yamashiro-Personal Tour | 08/30/99 | 1 |
| Ehrlich Tour | 08/31/99 | 3 |
| ANS meeting | 09/01/99 | 12 |
| Vice President for Research Tour | 09/02/99 | 2 |
| Nuclear Engineering Tour | 09/03/99 | 1 |
| EPA Tour | 09/07/99 | 1 |
| Panek-Personal Tour | 09/08/99 | 1 |
| Navy - USS Pennsylvania Tour | 09/09/99 | 6 |
| McCartney's Tour | 09/09/99 | 1 |
| Davison Baby Shower | 09/10/99 | 12 |
| Schindler-Personal Tour | 09/11/99 | 1 |
| Boy Scout Troop 423 Tour | 09/18/99 | 20 |
| Parents' Weekend Open House | 09/18/99 | 231 |
| Open House Volunteers | 09/18/99 | 1 |
| US Personnel Management Tour | 09/22/99 | 1 |
| E-College D.Com Tour | 09/24/99 | 1 |
| Virginia Power Tour | 09/24/99 | 1 |
| Wooten-Personal Tour | 09/27/99 | 1 |
| EMS Tour | 09/27/99 | 1 |
| OPP Tree-Trimming | 09/27/99 | 2 |
| OPP Tour | 09/29/99 | 2 |
| Review Committee Meeting | 09/29/99 | 5 |
| OPP Tour | 10/01/99 | 5 |
| Radiation Protection Tour | 10/01/99 | 1 |
| OPP Tour | 10/01/99 | 5 |

| Group Name | Date | # Visitors |
|---|---|---|
| Society for Physics Students Tour | 10/05/99 | 4 |
| NRC Inspector | 10/06/99 | 1 |
| Hoag's Catering | 10/07/99 | 1 |
| Hahn-Personal Tour | 10/08/99 | 1 |
| PSU Student Tour | 10/08/99 | 2 |
| PSU Student Tour | 10/12/99 | 1 |
| McCartney's Tour | 10/13/99 | 2 |
| OPP Tour | 10/14/99 | 1 |
| NucE Seminar Speaker | 10/15/99 | 2 |
| McCartney's Tour | 10/18/99 | 1 |
| Schindler-Personal Tour | 10/18/99 | 1 |
| C E 472W | 10/19/99 | 24 |
| News Agency Tour | 10/19/99 | 2 |
| Schindler-Personal Tour | 10/19/99 | 1 |
| IU-9 | 10/20/99 | 28 |
| Fuel Management Meeting | 10/20/99 | 2 |
| IU-9 | 10/20/99 | 20 |
| ENGR 097B | 10/20/99 | 19 |
| Gage Company | 10/21/99 | 1 |
| ME/NucE Staff Tour | 10/22/99 | 1 |
| Engineering Open House | 10/23/99 | 94 |
| Framatome Tour | 10/25/99 | 2 |
| Weiss Fellowship Tour | 10/27/99 | 10 |
| Rochester Gas Electric/GPU Nuclear Tour | 11/01/99 | 3 |
| Stone Valley Tour | 11/02/99 | 2 |
| RPI Tour | 11/04/99 | 2 |
| Beveridge-Personal Tour | 11/04/99 | 1 |
| Brush-Personal Tour | 11/04/99 | 1 |
| ANS Meeting | 11/04/99 | 6 |
| Boalsburg Learning Center Tour | 11/05/99 | 22 |
| Boalsburg Learning Center Tour | 11/05/99 | 21 |
| Dreibelbis-Personal Tour | 11/05/99 | 1 |
| NPTU - Interview | 11/05/99 | 1 |
| State College HS Chemistry Tour | 11/09/99 | 10 |

# *APPENDIX B*

## FORMAL TOUR GROUPS

| Group Name | Date | # Visitors |
|---|---|---|
| Boalsburg Elementary School Tour | 11/10/99 | 25 |
| Boalsburg Elementary School Tour | 11/10/99 | 25 |
| General Atomics Fuel Inspection | 11/11/99 | 1 |
| Radiation Protection Tour | 11/11/99 | 1 |
| Continuing & Distance Education Meeting | 11/12/99 | 1 |
| Morlang Family Tour | 11/12/99 | 6 |
| Chemistry Department Meeting | 11/12/99 | 1 |
| Plum Family Tour | 11/13/99 | 2 |
| Mortgage Source | 11/15/99 | 2 |
| Temp Interview | 11/16/99 | 1 |
| OPP Inspector | 11/16/99 | 1 |
| Shepherd College Tour | 11/16/99 | 8 |
| Staff Assistant Interview | 11/17/99 | 1 |
| Brownstead Family Tour | 11/19/99 | 5 |
| Environmental Interiors | 11/19/99 | 1 |
| Ripka Family Tour | 11/19/99 | 2 |
| Work Study Interview | 11/19/99 | 1 |
| PSU Employee Tour | 11/23/99 | 1 |
| Energy Institute Tour | 11/24/99 | 1 |
| Los Alamos Tour | 11/24/99 | 2 |
| Manning Family Tour | 11/24/99 | 2 |
| OPP Leak Investigation | 11/26/99 | 2 |
| Staff Assistant Interview | 11/29/99 | 1 |
| Staff Assistant Interview | 11/29/99 | 1 |
| Staff Assistant Interview | 11/29/99 | 1 |
| Staff Assistant Interview | 11/29/99 | 1 |
| Cobalt-60/Food Science Irradiation | 11/30/99 | 3 |
| Staff Assistant Second Interview | 12/01/99 | 1 |
| Staff Assistant Second Interview | 12/01/99 | 1 |
| Food Science Tour | 12/02/99 | 33 |
| McCormick Family Tour | 12/03/99 | 3 |
| Yamashiro-Personal Tour | 12/03/99 | 1 |
| Animal Science Tour | 12/03/99 | 1 |
| PSU Student Tour | 12/03/99 | 1 |

| Group Name | Date | # Visitors |
|---|---|---|
| Punxsutawney High School Tour | 12/06/99 | 10 |
| Environmental Interiors | 12/07/99 | 1 |
| Bechtel Bettis Tour | 12/08/99 | 5 |
| WPSX Tour | 12/08/99 | 1 |
| Winkelman Family Tour | 12/08/99 | 2 |
| Ciccarella-Personal Tour | 12/08/99 | 1 |
| Earth and Mineral Sciences Tour | 12/09/99 | 6 |
| OPP Tour | 12/09/99 | 2 |
| Chapman Family Tour | 12/14/99 | 6 |
| Eagle-Picher Tour | 12/15/99 | 2 |
| Kazmier-Personal Tour | 12/15/99 | 1 |
| Talbot Family Tour | 12/17/99 | 5 |
| Sarnoff Labs Tour | 12/20/99 | 3 |
| OPP Tour | 12/20/99 | 1 |
| Ghosh-Personal Tour | 01/03/00 | 1 |
| Weyandt-Medical Support Meeting | 01/04/00 | 1 |
| Cooper-Personal Tour | 01/04/00 | 1 |
| Pope Family Tour | 01/04/00 | 2 |
| Rodgers-Personal Tour | 01/05/00 | 1 |
| Pope Family Tour | 01/06/00 | 1 |
| Tavossi-Personal Tour | 01/07/00 | 1 |
| Yamashiro-Personal Tour | 01/07/00 | 1 |
| Schindler-Personal Tour | 01/09/00 | 1 |
| Safeguards Committee Meeting | 01/11/00 | 1 |
| Hoag's Catering | 01/11/00 | 1 |
| Mt Nittany Christian School Tour | 01/11/00 | 7 |
| OPP-Audio Visual Tour | 01/11/00 | 2 |
| Garman-Personal Tour | 01/11/00 | 1 |
| Herr-Personal Tour | 01/11/00 | 1 |
| Prospective Student Tour | 01/12/00 | 1 |
| Lehigh County EMA Tour | 01/13/00 | 3 |
| Northwestern High School Tour | 01/13/00 | 37 |
| PSU 012 | 01/13/00 | 3 |
| EDS Tour | 01/13/00 | 2 |

# *APPENDIX B*
## FORMAL TOUR GROUPS

| Group Name | Date | # Visitors |
|---|---|---|
| PSU 012 | 01/13/00 | 4 |
| OPP Tour | 01/14/00 | 3 |
| GMC Tour | 01/15/00 | 4 |
| PSU Students Tour | 01/17/00 | 2 |
| Junior Museum Tour | 01/17/00 | 16 |
| Pope-Personal Tour | 01/18/00 | 5 |
| ME NucE Students | 01/19/00 | 3 |
| Media Solutions Tour | 01/19/00 | 1 |
| ANS Meeting | 01/19/00 | 10 |
| PSU 012 | 01/20/00 | 3 |
| Carlin-Personal Tour | 01/20/00 | 1 |
| Varall-Personal Tour | 01/21/00 | 1 |
| Yamashiro-Personal Tour | 01/21/00 | 1 |
| OPP Tour | 01/24/00 | 2 |
| Cleaning Tour | 01/25/00 | 1 |
| Donley Baby Shower | 01/25/00 | 4 |
| OPP Tour | 01/26/00 | 1 |
| Test Loop Tour | 01/26/00 | 1 |
| Test Loop Tour | 01/26/00 | 1 |
| PSU Student Tour | 01/27/00 | 1 |
| Environ. Health and Safety/EPA Training | 01/27/00 | 1 |
| Property Inventory | 01/28/00 | 2 |
| Upward Bound Tour | 01/29/00 | 14 |
| CI 295 | 02/01/00 | 21 |
| OPP Tour | 02/02/00 | 4 |
| OPP Tour | 02/02/00 | 1 |
| Pope Family Tour | 02/02/00 | 1 |
| CI 295 | 02/03/00 | 25 |
| Bettis Tour | 02/03/00 | 2 |
| Research Assistant Interview | 02/04/00 | 1 |
| OPP Tour | 02/04/00 | 2 |
| PSU Student Tour | 02/04/00 | 1 |
| Research Assistant Interview | 02/07/00 | 1 |
| OPP Tour | 02/09/00 | 8 |

| Group Name | Date | # Visitors |
|---|---|---|
| Brigandi-Personal Tour | 02/15/00 | 1 |
| University Police Training | 02/15/00 | 9 |
| Electric Motor Tour | 02/17/00 | 2 |
| Berwick High School Tour | 02/17/00 | 14 |
| Navy Tour | 02/17/00 | 2 |
| Weinsteiger-PSU Student Tour | 02/17/00 | 1 |
| University Police Training | 02/22/00 | 12 |
| CI 295 Student Tour | 02/23/00 | 1 |
| ANS Meeting | 02/23/00 | 3 |
| PSU Employee Tour | 02/24/00 | 1 |
| Mt View Christian School | 02/24/00 | 22 |
| Synetix Tour | 02/29/00 | 1 |
| University Police Training | 02/29/00 | 14 |
| TWM Inc. Tour | 03/01/00 | 1 |
| OPP Tour | 03/01/00 | 2 |
| Yamashiro-Personal Tour | 03/03/00 | 1 |
| PSU Grad Student Tour | 03/03/00 | 1 |
| Schindler-Personal Tour | 03/03/00 | 1 |
| AmeriGas Tour | 03/07/00 | 1 |
| Paulson-Personal Tour | 03/09/00 | 1 |
| Gates-Personal Tour | 03/10/00 | 1 |
| Nalco Chemical Company Tour | 03/10/00 | 1 |
| Junior Science & Humanities Tour | 03/13/00 | 11 |
| Boehme-Personal Tour | 03/14/00 | 1 |
| Wagner-Personal Tour | 03/14/00 | 1 |
| Eng. and Applied Science Interest House | 03/14/00 | 13 |
| Lab Experiment | 03/15/00 | 1 |
| Brown-Personal Tour | 03/17/00 | 2 |
| Hartigan-Personal Tour | 03/17/00 | 1 |
| Bettis Tour | 03/20/00 | 2 |
| OPP Tour | 03/21/00 | 3 |
| Guzman-Personal Tour | 03/22/00 | 1 |
| Junior Museum of Central PA Tour | 03/22/00 | 12 |
| ANS Meeting | 03/22/00 | 1 |

# *APPENDIX B*

FORMAL TOUR GROUPS

| Group Name | Date | # Visitors |
|---|---|---|
| Dawson-Personal Tour | 03/23/00 | 1 |
| PSU Alumni Tour | 03/23/00 | 1 |
| IPAC Tour | 03/23/00 | 1 |
| PSU Engineering Student Tour | 03/24/00 | 1 |
| Park Forest Middle School Tour | 03/24/00 | 24 |
| PSU Student Tour | 03/24/00 | 2 |
| Spend an Engineering Day Tour | 03/25/00 | 54 |
| Manahan-Personal Tour | 03/28/00 | 1 |
| Grove City College Tour | 03/29/00 | 13 |
| OPP Tour | 03/29/00 | 1 |
| U.S. Army Tour | 03/30/00 | 1 |
| Central High School Tour | 04/03/00 | 30 |
| OEA Tour | 04/03/00 | 1 |
| Hoag's Catering | 04/04/00 | 1 |
| Food Science 430 | 04/04/00 | 3 |
| Greensburg Salem High School Tour | 04/05/00 | 20 |
| Hoag's Catering | 04/04/00 | 2 |
| Demoss-Personal Tour | 04/05/00 | 1 |
| Sipos-Former RSEC Employee Tour | 04/06/00 | 1 |
| Boy Scouts Tour | 04/06/00 | 10 |
| Altoona High School Tour | 04/07/00 | 42 |
| Jaus-Personal Tour | 04/07/00 | 1 |
| Dussinger Family Tour | 04/07/00 | 2 |
| Prospective Students Tour | 04/10/00 | 3 |
| Materials Science Tour | 04/10/00 | 17 |
| Human Resources Tour | 04/11/00 | 2 |
| Cranberry High School Tour | 04/11/00 | 13 |
| Flarend-Personal Tour | 04/11/00 | 1 |
| Salvage & Surplus | 04/12/00 | 1 |
| Daniel Boone High School Tour | 04/17/00 | 13 |
| Food Science 105 | 04/17/00 | 5 |
| NucE 450 | 04/18/00 | 7 |
| Juniata College Tour | 04/18/00 | 6 |
| Carlin-Personal Tour | 04/19/00 | 1 |

| Group Name | Date | # Visitors |
|---|---|---|
| AC Engineer | 04/19/00 | 1 |
| Stat 401 Project | 04/19/00 | 2 |
| Paynter-Personal Tour | 04/20/00 | 1 |
| Wyrick Family Tour | 04/20/00 | 2 |
| Carlin-Personal Tour | 04/21/00 | 1 |
| NucE/ME Tour | 04/21/00 | 1 |
| PTI Tour | 04/21/00 | 2 |
| PSU Student Tour | 04/21/00 | 1 |
| Crock-Former PSU Employee Tour | 04/22/00 | 1 |
| Dreibelbis Family Tour | 04/22/00 | 4 |
| FBI Tour | 04/25/00 | 1 |
| OPP Tour | 04/25/00 | 1 |
| Biochemistry/Molecular Bio. Co-60 Irradiation | 04/26/00 | 2 |
| Bowersox-Personal Tour | 04/26/00 | 1 |
| OPP Tour | 04/27/00 | 5 |
| Wyomissing High School Tour | 04/27/00 | 6 |
| "Take Our Daughters To Work" Tour | 04/27/00 | 17 |
| Christman-Personal Tour | 04/27/00 | 1 |
| DTRA Review | 04/27/00 | 7 |
| OPP Tour | 04/28/00 | 2 |
| St. Mary's High School Tour | 04/28/00 | 41 |
| Hartigan-Personal Tour | 05/02/00 | 1 |
| Manheim Township Supervisors Tour | 05/03/00 | 18 |
| PSU Student Tour | 05/04/00 | 1 |
| Horticulture Experiment | 05/05/00 | 2 |
| Cambria Heights High School Tour | 05/05/00 | 39 |
| Tyrone Middle School Tour | 05/05/00 | 60 |
| Kane High School Tour | 05/09/00 | 9 |
| Forklift Tour | 05/09/00 | 2 |
| University Police/Parking Office- Ticketing | 05/09/00 | 1 |
| Ice Pavillion Staff Tour | 05/09/00 | 2 |
| Freeman-Personal Tour | 05/10/00 | 1 |
| NucE Graduation Tour | 05/11/00 | 5 |
| PSU Student Tour | 05/11/00 | 4 |

# *APPENDIX B*

## FORMAL TOUR GROUPS

| Group Name | Date | # Visitors |
|---|---|---|
| Wolf-Personal Tour | 05/12/00 | 1 |
| Camp Hill High School Tour | 05/12/00 | 13 |
| Wenner Family Tour | 05/12/00 | 8 |
| Walton-Personal Tour | 05/15/00 | 1 |
| Environmental Health & Safety/EPA Training | 05/15/00 | 1 |
| OPP Tour | 05/17/00 | 1 |
| Huntington High School Tour | 05/19/00 | 14 |
| Altoona Neon Sign Service | 05/22/00 | 2 |
| Danville High School Tour | 05/23/00 | 33 |
| Bellefonte Middle School Tour | 05/23/00 | 2 |
| Public Relations-EPP Review | 05/24/00 | 1 |
| PSU Graduate Student Tour | 05/24/00 | 1 |
| Bellefonte Middle School Tour | 05/26/00 | 3 |
| Kenney Family Tour | 06/01/00 | 4 |
| Earth & Mineral Sciences Tour | 06/01/00 | 2 |
| Redlon & Johnson Tour | 06/01/00 | 1 |
| Bettis Tour | 06/01/00 | 7 |
| PSU Graduate Student Tour | 06/06/00 | 1 |
| OPP Tour | 06/07/00 | 1 |
| Brown-Personal Tour | 06/08/00 | 1 |
| Bellefonte High School Tour | 06/08/00 | 3 |
| Weyandt-Medical Support Meeting | 06/09/00 | 1 |
| Sears Family Tour | 06/12/00 | 1 |
| Computer Support Specialist Interview | 06/13/00 | 1 |

| Group Name | Date | # Visitors |
|---|---|---|
| Rod Bundle Heat Transfer | 06/14/00 | 2 |
| Chmielewski Family Tour | 06/20/00 | 4 |
| WISE Tour | 06/20/00 | 17 |
| WISE Tour | 06/20/00 | 16 |
| SOARS Tour | 06/20/00 | 24 |
| Chmielewski-Personal Tour | 06/21/00 | 1 |
| Perkin Elmer Tour | 06/21/00 | 1 |
| High School Interns Tour | 06/21/00 | 9 |
| Maintenance & Operations Tour | 06/22/00 | 2 |
| Ikon Office Solutions Tour | 06/22/00 | 1 |
| Valic Tour | 06/22/00 | 1 |
| Ikon Office Solutions Tour | 06/22/00 | 1 |
| ME Graduate Student Tour | 06/22/00 | 1 |
| Nuclear Measurements Tour | 06/23/00 | 1 |
| Gould Family Tour-Former RSEC Staff | 06/26/00 | 2 |
| BM Kramer Tour | 06/27/00 | 2 |
| Ripka Family Tour | 06/28/00 | 1 |
| Philip Services Tour | 06/29/00 | 1 |
| Nuclear Engineering Students Tour | 06/30/00 | 6 |
| Ikon Office Solutions Tour | 06/30/00 | 1 |
| | | |
| Tour Group Total | | 2440 |