PENNSTATE

College of Engineering
Radiation Science and Engineering Center

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

Annual Operating Report, FY 03-04
PSBR Technical Specifications 6.6.1
License R-2, Docket No. 50-5

December 16, 2004

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, 2003 through June 30, 2004, 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-Ninth 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
A001

PENN STATE BREAZEALE REACTOR

Annual Operating Report, FY 03-04
PSBR Technical Specifications 6.6.1
License R-2, Docket No. 50-5

Reactor Utilization

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

EDUCATION utilization is primarily in the form of laboratory classes conducted for graduate and undergraduate students and numerous high school science groups. These classes vary from neutron activation analysis of an unknown sample to the calibration of a reactor control rod. In addition, an average of 2500 visitors tour the PSBR facility each year.

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

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

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

Between July 1, 2003 and June 30, 2004, the PSBR was

critical for	1070 hours	or 3.9 hrs/shift
subcritical for	417 hours	or 1.5 hrs/shift
used while shutdown for	657 hours	or 2.4 hrs/shift
not available	11 hours	or 0.0 hrs/shift
Total usage	2155 hours	or 7.9 hrs/shift

The reactor was pulsed a total of 116 times with the following reactivities:

< $2.00	11
$2.00 to $2.50	96
> $2.50	9

The square wave mode of operation was used 62 times to power levels between 100 and 500 KW.

Total energy produced during this report period was 736 MWH with a consumption of 38 grams of U-235.

Unscheduled Shutdowns - Tech Specs requirement 6.6.1.b.

The five unplanned shutdowns during the July 1, 2003 to June 30, 2004 period are described below.

On August 8, 2003, a Watchdog Scram occurred while at 900 kW during a run against the fast neutron irradiator. The operator had noted a downward spike in power and went to the special screen to print out the event. He hit "print screen" and then realized he needed to freeze the screen first. He hit "freeze" and then hit "print screen" again. The watchdog scram occurred in about 30 seconds. Hitting the "print screen" twice in close succession caused an overload of the

CPU of the DCC-X control computer. The event was duplicated at shutdown. This software defect had already been identified by AECL as a software change request and was fixed in the console software upgrade of August 2004.

On September 26, 2003, during operation in 3-rod auto mode at 800 kW, the reactor operator observed that the shim and regulating rods were adjusting to xenon changes but that the safety rod was remaining fixed in position. Manually moving the transient rod would cause the shim and regulating rods to move in response, but again the safety rod remained fixed in position. The control system was then put into manual mode and attempts to move the safety rod were unsuccessful. The transient, shim and regulating rods were then moved to their lower limits shutting down the reactor. The safety rod was then scrammed from its position to verify that its scram function was operable. Even though the safety rod could not be moved by its rod drive, the Tech Spec was not violated since the Tech Spec requirement is for three rods to be operable. AP-13, Maintenance/Repair, was initiated. The investigation revealed that the pinion drive had drag on the center mounting plate. The center was machined but there was still drag of the armature rubbing against the inside of the mounting plate. This rubbing had been taking place over time and had galled the surface. The mounting plate was again machined to fix this problem. Following re-assembly and testing of the rod drive and motor, CCP-1 was performed to measure rod drive times and rod drop time which were satisfactory.

On October 7, 2003, the reactor operator tripped the reactor during operation at 750 kW upon receipt of a building fire alarm. The building was evacuated. An investigation revealed that a mechanical contractor grinding concrete in the Cobalt-60 facility basement created excess dust that caused the smoke detector to initiate an alarm. During earlier contractor work, the smoke detector had been bagged and bypassed, but had been returned to normal service following the initial work.

On November 3, 2003, during square wave operation at 84 kW, the DCC-Z monitoring computer froze during an attempt to print the square wave data. The printer did not respond to the first print screen command and was found to be jammed. The jam was cleared and then a second print screen caused the DCC-Z shutdown. The operator then shut down the reactor. This was similar to the event of August 8, 2003 on DCC-X. Pressing the "print screen" twice in close succession can cause an overload of the computer CPU. This software defect had previously been identified by AECL as a software change request and was fixed in the console software upgrade of August 2004.

On January 7, 2004, a reactor trip occurred approximately 30 seconds after reaching 800 kW when a Wide Range RSS (reactor safety system) "Fission Chamber Detector Voltage Low" scram occurred. AP-4, Event Evaluation, and AP-13, Maintenance/Repair, procedures were initiated. No conclusions could be reached during troubleshooting of the Wide Range pre-amp and high voltage supply. However, as a precautionary measure both components were replaced. CCP-7, Wide Range Channel Electronic Checks, was then completed. Following CCP-7, the reactor was taken to 1 MW in steps to confirm Wide Range channel and fuel temperature channel indications against previous data; the comparison of operating data indicated a conservative operation. Normal operations were resumed.

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 reporting period.

Major Changes Reportable Under 10 CFR 50.59 - Tech Specs requirement 6.6.1.d.

Facility Changes -

On April 15, 2004, the DCC-X CRT monitor was replaced with an LCD monitor. A screening found no applicability under 50.59. The DCC-X monitor provides no safety function and provides monitoring only.

Procedures -

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

New Tests and Experiments -

None

Radioactive Effluents Released - Tech Specs requirement 6.6.1.e.

Liquid

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

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

Gaseous

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

The amount of Ar-41 released from the reactor pool is very dependent upon the operating power level and the length of time at power. The release per MWH is highest for extended high power runs and lowest for intermittent low power runs. The concentration of Ar-41 in the reactor bay and the bay exhaust was measured by the Radiation Protection staff during the summer of 1986. Measurements were made for conditions of low and high power runs simulating typical operating cycles. Based on these measurements, an annual release of between 558 mCi and 1693 mCi of Ar-41 is calculated for July 1, 2003 to June 30, 2004, resulting in an average concentration at ground level outside the reactor building that is 0.9 % to 2.7 % 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 343 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 343 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 3.3 %.

Production and release of Ar-41 from reactor neutron beam ports was minimal. Beam port #7 has only three small (1/2 inch diameter) collimation tubes exiting the port and any Ar-41 production in these small tubes is negligible. Beam port #4 has an aluminum cap installed inside the outer end of the beam tube to prevent air movement into or out of the tube as the beam port door is opened or closed. The estimated Ar-41 production in beam port #4 for all beam port operations is 68 mCi. With the aforementioned aluminum cap in place, it is assumed that this Ar-41 decayed in place. Radiation Protection Office air measurements have found no presence of Ar-41 with the beam port cap in place.

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

Tritium release from the reactor pool is another gaseous release. The evaporation rate of the reactor pool was checked previously by measuring the loss of water from a flat plastic dish floating in the pool. The dish had a surface area of 0.38 ft^2 and showed a loss of 139.7 grams of water over a 71.9 hour period giving a loss rate of 5.11 g ft^{-2} hr^{-1}. Based on a pool area of about 395 ft^2 the annual evaporation rate would be 4680 gallons. This is of course dependent upon relative humidity, temperature of air and water, air movement, etc. For a pool ^3H concentration of 37094 pCi/l (the average for July 1, 2003 to June 30, 2004) the tritium activity released from the ventilation system would be 657 μCi. A dilution factor of 2 x 10^8 ml s^{-1} was used to calculate the unrestricted area concentration. This is from 200 m^2 (cross-section of the building) times 1 m s^{-1} (wind velocity). These are the values used in the safety analysis in the reactor license. A sample of air conditioner condensate a previous year showed no detectable ^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	657 μC
Average concentration, unrestricted area	1.04 x 10^{-13} μCi/ml
Permissible concentration, unrestricted area	1 x 10^{-7} μCi/ml
Percentage of permissible concentration	1.04 x 10^{-4} %
Calculated effective dose, unrestricted area	5.21 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, 2003 to June 30, 2004 period.

	3rd Qtr '03	4th Qtr '03	1st Qtr '04	2nd Qtr '04	Total
Fence North	26.0	28.8	21.5	29.3	105.6
Fence South	25.0	28.4	22.3	30.7	106.4
Fence East	26.6	29.3	23.1	25.3	104.3
Fence West	23.5	28.6	21.3	28.9	102.3
Control	23.0	27.6	20.5	23.2	94.3
Control	22.2	23.2	19.0	21.6	86.0

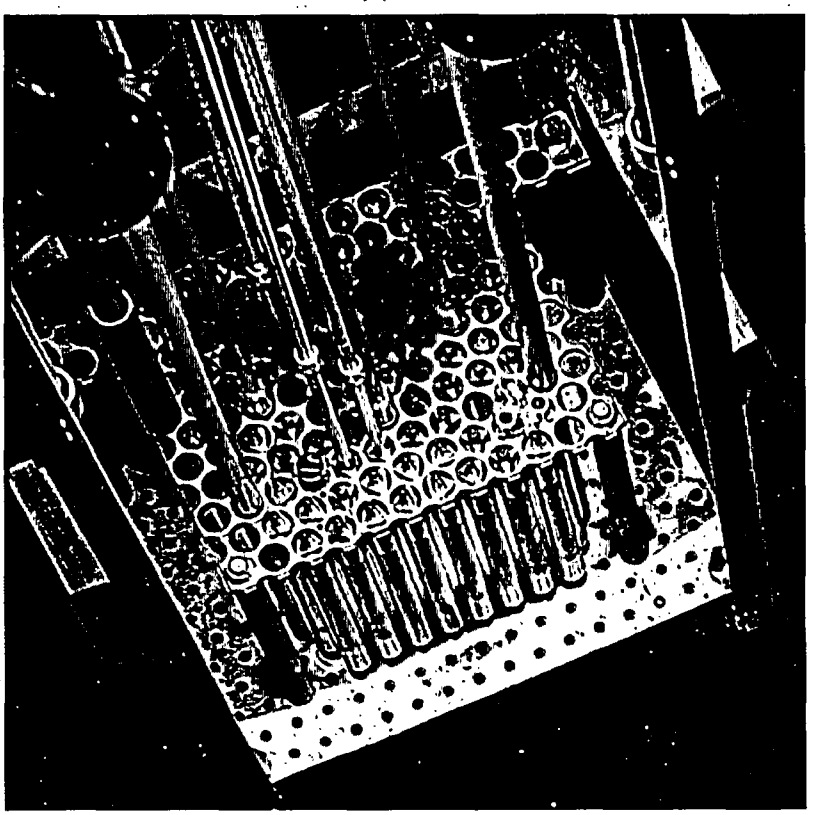
Personnel Exposures - Tech Specs requirement 6.6.1.g.

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

PENN STATE UNIVERSITY

Radiation Science & Engineering Center

49th Annual Progress Report



College of Engineering
Breazeale Nuclear Reactor
University Park, PA

December 2004

PENNSTATE
1855

49TH ANNUAL PROGRESS REPORT

PENN STATE RADIATION SCIENCE & ENGINEERING CENTER

July 1, 2003 to June 30, 2004

Submitted to:

United States Department of Energy

and

Penn State

By:

C. Frederick Sears (Director)
Kenan Ünlü (Associate Director for Research)
Terry L. Flinchbaugh (Associate Director for Operations)
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University Park, PA 16802

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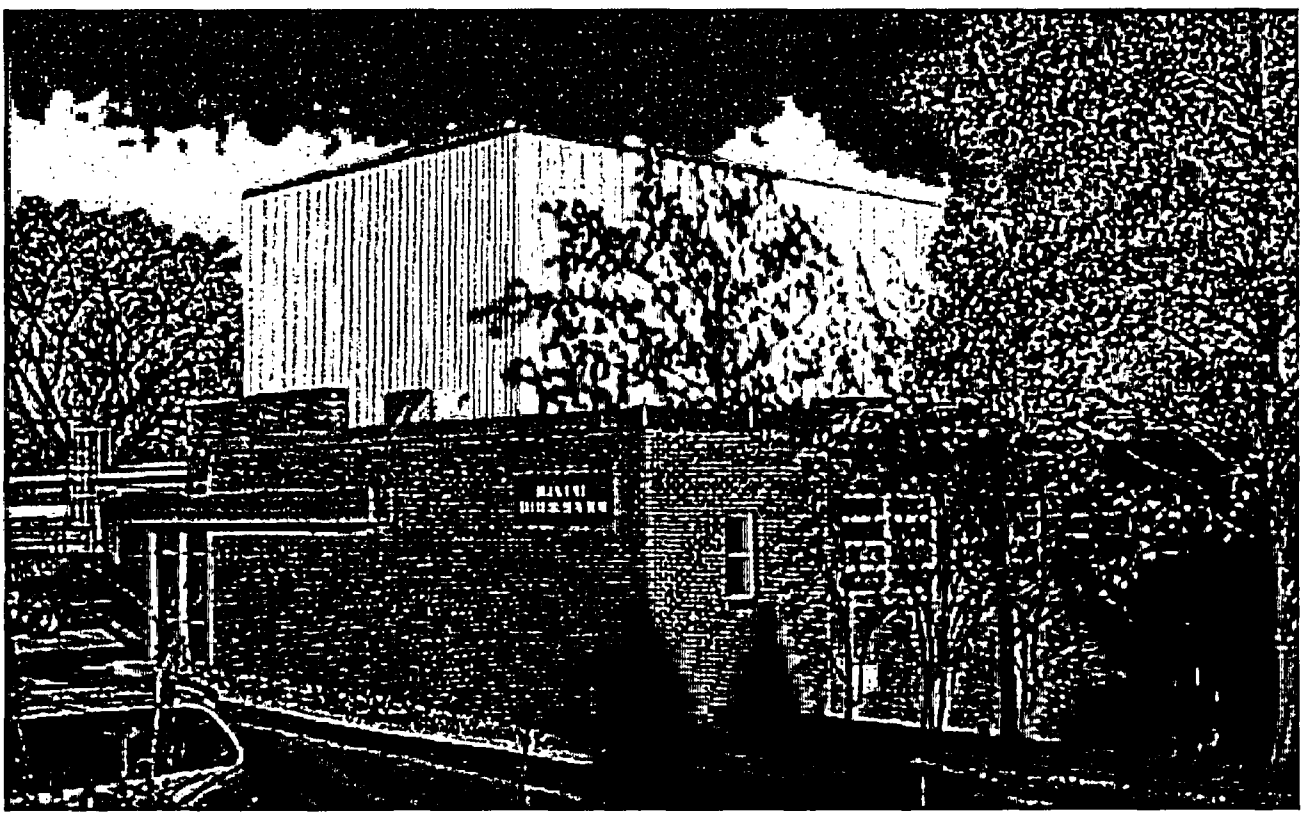
PREFACE

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

The Penn State University Radiation Science and Engineering Center's 49th Annual Progress Report (July 2003 through June 2004) is submitted in accordance with the requirements of Contract DE-AC07-99ID13727 between the United States Department of Energy and Bechtel (BWXT Idaho), and their Contract 00036822 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 Angela Pope who edited the report. Special thanks are extended to those responsible for the individual sections as listed in the table of contents and to the individual facility users whose research summaries are compiled in Section XII.

INTRODUCTION



MISSION

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

The RSEC facilities have a diverse and dedicated staff with a commitment to safety, excellence, quality, user satisfaction, and education by example and teaching.

VISION

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 nuclear and personal safety in everything we do.

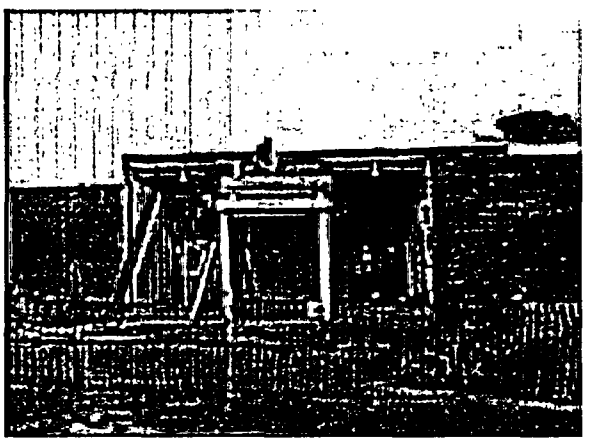
Education—Develop and deliver innovative educational programs to advance societal knowledge of nuclear science and engineering through resident instruction and continuing education for students of all ages and their educators.

Research—Expand leading edge research that increases fundamental knowledge of nuclear science and engineering particularly in the area of materials research applications of nuclear techniques.

Service—Expand and build a diverse array of services and users by maintaining excellence, quality, user satisfaction, and efficient service to supplement university funding 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:

- During this fiscal year the lobby was expanded and is now fully functional. The new lobby provides 400 square feet of additional space to handle the visitors and students. A common room for staff for copying, storage, kitchenette facilities and related administrative tasks was added. All of the new areas are ergonomically designed with modern furnishings. The exterior of the lobby was designed to be aesthetically pleasing yet provide maximum security. The entire project was unique in that it had to be accomplished while maintaining building integrity and reactor facility containment during all phases of construction. The project was completed in a period of only 13 weeks.



- Architectural plans for the RSEC expansion for a new Neutron Beam Hall and Neutron Beam Ports facilities are completed. Working with a professional architectural firm, a contractor, and related personnel from various university functions, we obtained a firm estimate for the expansion cost. Internal benefactors of the new neutron beam facilities are identified. We obtained support letters or expression of interests from about 30 faculty members from four different colleges within the university. More than half of the total budget for expansion is currently available, and efforts to raise the remaining portion of budget continue.

- Considerable faculty and staff effort was rewarded when DOE issued the INIE (Innovations in Nuclear Infrastructure and Education) grants. The INIE Big-Ten Consortium, led by Penn State and comprised of Penn State, Purdue University, the University of Illinois and the University of Wisconsin received approximately $1.97 million per year in FY02 and FY03. The Ohio State University and the University of Michigan joined the Big-Ten Consortium during this fiscal year and the consortium funding was increased to $ 2.1 million per year. Currently, DOE plans to continue the grant program for at least three additional years. The objective of the INIE program is to strengthen the nation's university nuclear engineering programs through innovative use of the university research and training reactors. During the two-year period of the INIE grant the following was accomplished at Penn State –
  - The Room 2 laboratory/classroom was totally refurbished and equipped with state of the art computer work stations and audio-visual equipment.
  - A refurbished GammaCell was purchased, and installed during the '02-'03 fiscal year. The upgraded Cobalt-60 loading decreased irradiation times by a factor of ten, providing much better service for campus users.
  - A slow neutron chopper system was developed with a chopper brought from the Cornell University, Ward Center for Nuclear Sciences to characterize the neutron beam used for radiography and radioscopy. As part of the INIE grant, this system is available for loan to other research reactors. As part of neutron beam characterization efforts, a He-3 neutron spectrometer system was ordered to determine the spectrum of high-energy neutrons.
  - Mini-grants were awarded on a competitive basis to Penn State and non-Penn State individuals submitting proposals to use the Penn State Radiation Science and Engineering Center facilities.
  - Efforts continue to lay the groundwork for the development of a cold neutron beam and new neutron beam port facilities. Both thermal and thermo-hydraulic behavior of two University based cold neutron sources are being evaluated in order to build a third generation mesitylene based cold neutron source at Penn State. Code development also continues to model the existing beam ports and various future designs.
  - Dr. Kenan Ünlü, and Drs. Vijaykrisnan Narayanan and Mary Jane Irwin of the Department of Computer Science and Engineering continue testing of neutron induced soft errors in semiconductor memories and started to develop a soft error analysis toolset program.
  - Drs. Jack Brenizer, Matthew Mench, Kenan Ünlü, and Abel Chuang of the Department of Mechanical and Nuclear Engineering continue major research projects using neutron radioscopy and neutron radiography for investigation of fuel cells for several major automotive companies. Several other companies used the beam facilities for radiography and radioscopy projects, some of which were associated with NASA's space shuttle program.
  - Dr. Kenan Ünlü, and Dr. Peter I. Kuniholm from Cornell University continue neutron activation analysis of absolutely dated tree rings to identify climatically significant marker events in history and prehistory.
- The project to upgrade the reactor control system hardware and software continued during the year. (Installation and all necessary testing of the new system was completed in the new fiscal year.)
- The neutron irradiation of semi-conductors for commercial, military, and space applications continued at a very healthy pace.

- The use of neutron radioscopy and neutron transmission as a research and service tool to industry continued at a very high level during the year with increasing interest by companies who fabricate boron containing metals used in the nuclear industry. Efforts are under way to upgrade the software and hardware associated with this work.

- Income from service work done for industrial users was used to continue the support of three Ph.D. graduate students in the nuclear engineering program. Two students are working in the area of modeling the Penn State TRIGA reactor core and developing better computer code tools for fuel depletion tracking and core loading designs. The third student completed work in the area of thermal-hydraulic modeling of the TRIGA core.

- Numerous high school, Penn State, and non-Penn State 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. The facility hosted more than 1700 visitors during the fiscal year. A complete list of groups hosted is presented in Appendix B.

- Increased reactor usage for University courses continued this year as multiple sessions were needed in the NucE 451 and NucE 450 laboratory courses. An increased emphasis on graduate students taking NucE 444, Nuclear Reactor Operations, resulted in more reactor usage during the year.

- In light of concern for terrorist activities that could be directed against university research reactors, continuing efforts were made in expanding the total scope of facility security. Additional attention to security issues is expected to continue, both self-directed and in response to NRC guidance. The staff is meeting the challenge of providing security without compromising the education and research mission of the reactor facility.

PERSONNEL

PERSONNEL

Several undergraduate students worked in work-study or wage payroll positions during the year. Daniel Skilone, Ashley Talley, Aaron Wilmot, and Doug Yocum assisted Candace Davison in facility educational programs for high school students. Jared Hoover, Fernando Palacios and Brian Pye assisted Dr. Kenan Ünlü on research projects.

Undergraduate Rachel Slaybaugh began training as a reactor operator during summer 2003 and received her reactor operator's license in June 2004. Undergraduates Adina LaFrance and Joshua LaFrance were hired to begin training as senior reactor operators in January 2004 and received their senior reactor operator's licenses in June 2004. Both Adina and Joshua had previous nuclear navy experience. Undergraduate Bert Tredway began training as a senior reactor operator in October 2003, but resigned from the program in January 2004.

Figure 1. Reactor Operator Interns, Rachel Slaybaugh (front), Joshua LaFrance and Adina LaFrance (back).

Undergraduate Chanda Decker who was already licensed as a reactor operator, received her senior reactor operator's license in June 2004.

Randy McCullough, instrumentation engineer, resigned his position on July 31, 2003. Randy was also licensed as a reactor operator. Eric Knepp was hired into the engineering aide position on Sep. 2, 2003, and began training for a reactor operator's license.

Figure 2. Candace Davision, Senior Reactor Operator, Adam Koziol, Senior Reactor Operator Intern, and Brenden Heidrich, Senior Reactor Operator.

Two staff promotions occurred during the year. Terry Flinchbaugh was promoted from manager, operations and training, to associate director for operations. Ron Eaken was promoted from a machinist A grade 2 position to a reactor machinist grade 1 position in technical service.

The following changes to the membership of the Penn State Reactor Safeguards Committee (PSRSC) were effective on Jan. 1, 2004. Committee chair Larry Hochreiter (professor, nuclear engineering, Penn State) completed his second term on the committee and was not eligible for re-appointment. Randy Tropasso (manager of nuclear design, Exelon Nuclear) was reappointed to a second term.

Eric Boeldt (manager of radiation protection, Penn State) was reappointed to the committee. The committee member with health physics expertise can serve an indefinite number of consecutive terms. Committee member Tom Litzinger assumed the chairmanship of the committee upon Hochreiter's departure. Yousry Azmy (professor, nuclear engineering, Penn State) was appointed to the committee.

TABLE 1

	Faculty and Staff	Title
	Jack S. Brenizer	Professor & Program Chair, Nuclear Engineering
**	Mac E. Bryan	Research Engineer/Supervisor, Reactor Operations
	Gary L. Catchen	Professor, Nuclear Engineering
**	Thierry H. Daubenspeck	Activation & Irradiation Specialist/Supervisor, Reactor Operations
**	Candace C. Davison	Research & Education Specialist/Supervisor, Reactor Operations
**	Chanda C. Decker	Reactor Operator Intern
	Wendy R. Donley	Staff Assistant VII
	Ronald L. Eaken	Reactor Machinist
**	Terry L. Flinchbaugh	Associate Director for Operations
**	Brenden J. Heidrich	Research Assistant
	Eric G. Knepp	Engineering Aide
**	Adam W. Kozial	Reactor Operator Intern
**	Adina K. LaFrance	Reactor Operator Intern
**	Joshua A. LaFrance	Reactor Operator Intern
	Jana Lebiedzik	Research Support Technician III
*	Randy A. McCullough	Instrumentation Engineer (resigned)
**	Gary M. Morlang	Senior Supervisor/Reactor Engineering Operations
	Jeremy M. Myers	Computer Support Specialist
	Angela D. Pope	Staff Assistant V
**	Alison R. Portanova	Research & Service Support Specialist/Supervisor, Reactor Operations
	Paul R. Rankin	Radiation Measurement Technician
**	Bret M. Rickert	Reactor Operator Intern
	Susan K. Ripka	Administrative Aide III
**	C. Frederick Sears	Senior Scientist/Director, RSEC, Associate Professor, Nuclear Engineering
*	Rachel N. Slaybaugh	Reactor Operator Intern
	Sally Thomas	Staff Support
	Kenan Ünlü	Senior Scientist/Associate Director for Research, Professor, Nuclear Engineering

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

Wage Payroll/Work Study	
Jared Hoover	Ashley Talley
Fernando Palacios	Bert Tredway
Brian Pye	Aaron Wilmot
Daniel Skilone	Doug Yocum

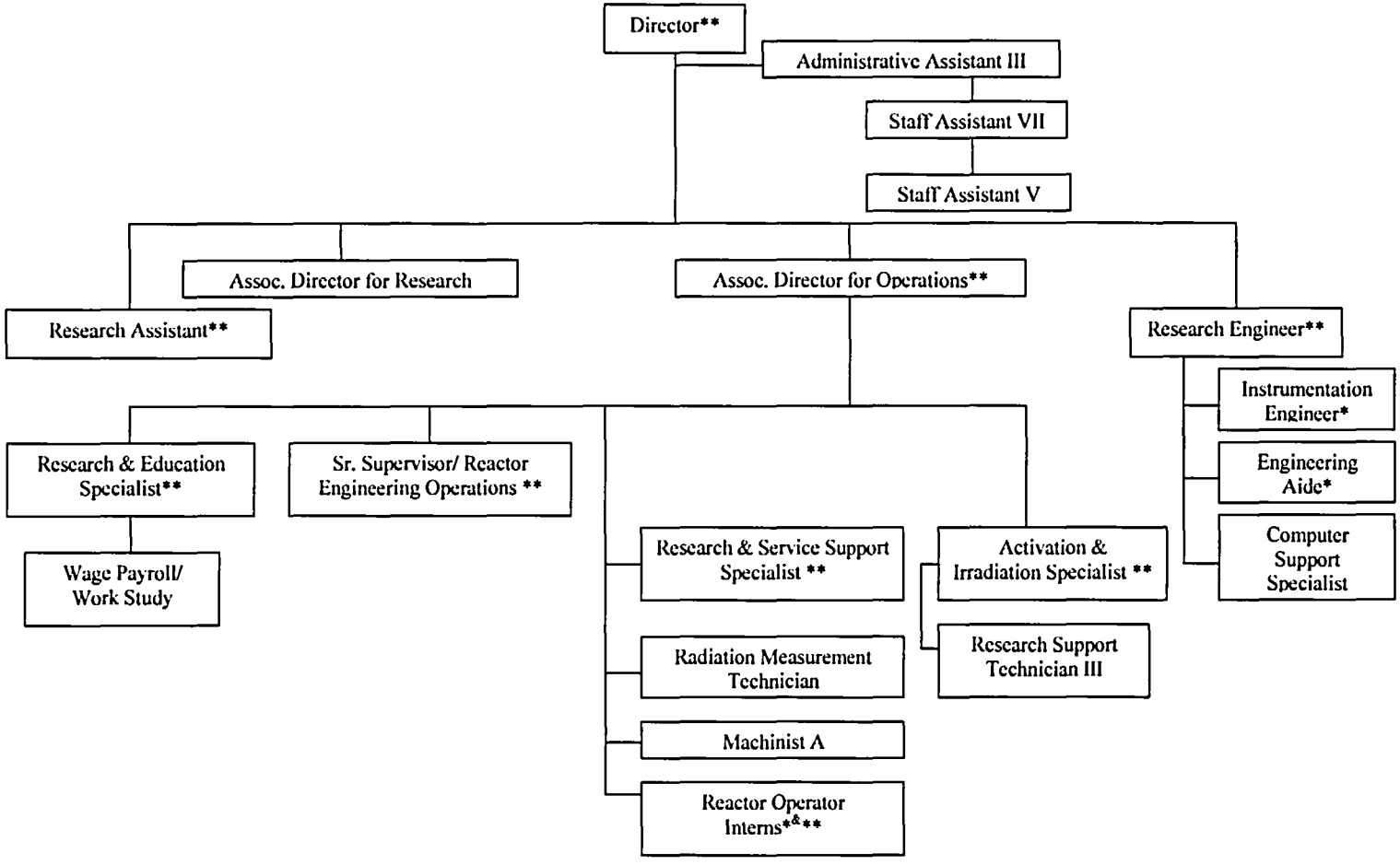
TABLE 2

	Penn State Reactor Safeguards Committee	
**	Y. Azmy	Professor of Nuclear Engineering, Penn State
	R. Benson	Professor & Dept. Head, Mechanical & Nuclear Engineering, Penn State
***	E. Boeldt	Manager, Radiation Protection, Penn State Environmental Health & Safety
	F. Eisenhuth	Sr. Engineer, Pennsylvania Power & Light Susquehanna Steam Electric Station
*	L. Hochreiter, Chairman	Professor, Mechanical & Nuclear Engineering, Penn State
	K. Ivanov	Associate Professor in Charge of Fuel Management, Penn State
****	T. Litzinger, Chairman	Professor & Director of Leonhard Center, Penn State
	I. McMaster	Retired Deputy Director, RSEC
	G. Robinson	Professor Emeritus, Nuclear Engineering, Penn State
	C.F. Sears	Ex-Officio, Director RSEC
***	R. Tropasso	Manager of Nuclear Design, Exelon

* *Served through January 1, 2004*
** *Initial Appointment January 1, 2004*
*** *Reappointed effective January 1, 2004*
**** *Assumed Chairmanship on January 1, 2004*

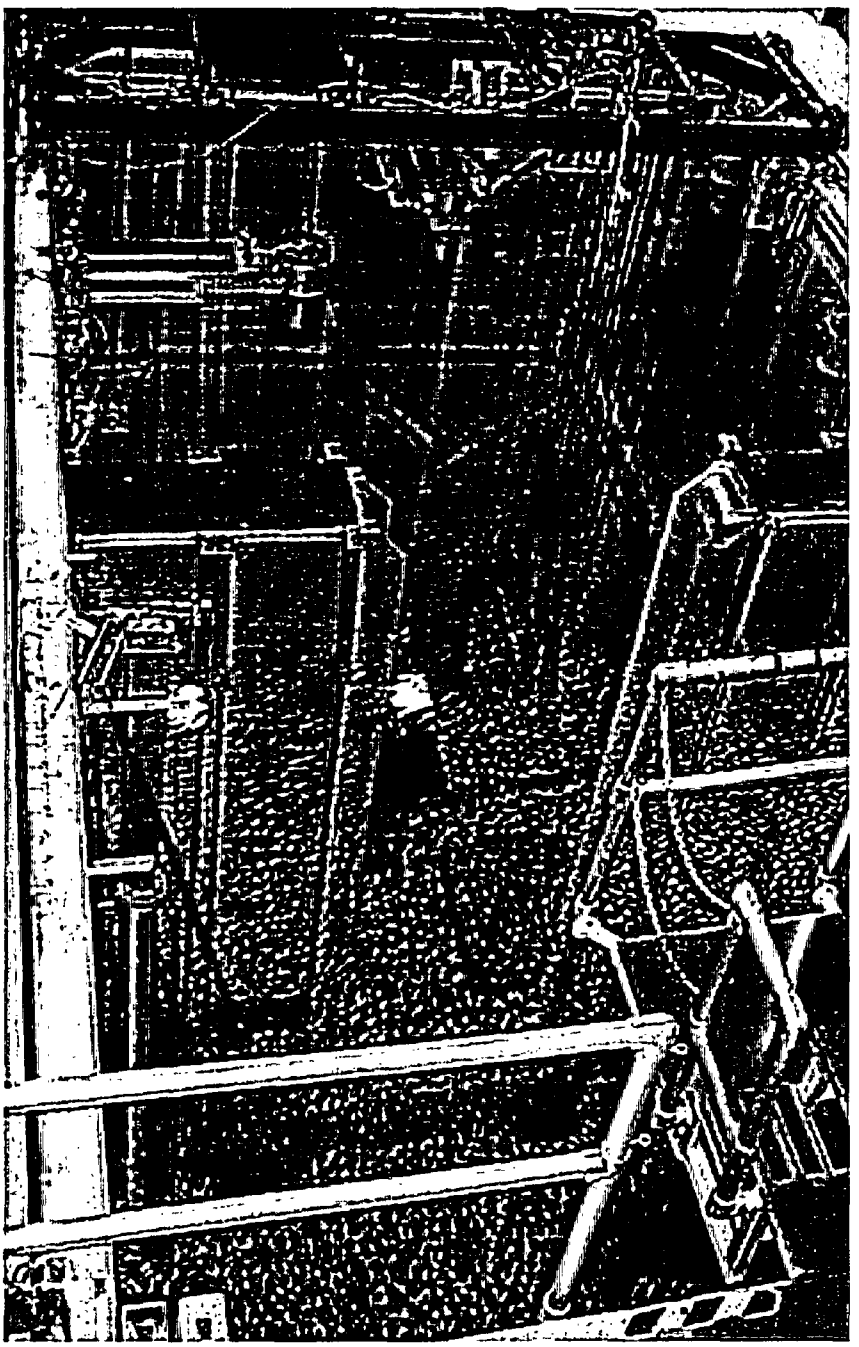
FIGURE 1

RSEC Organization Chart



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

REACTOR OPERATIONS



REACTOR OPERATIONS

Research reactor operation began at Penn State in 1955. In December 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 is 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:

Education
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 depth profiling, neutron radiography, gamma irradiation, several 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.

Figure 1. Mac Bryan operates at the reactor console.

OPERATIONS

The PSBR core, containing about 7.5 pounds of Uranium-235 in a non-weapons form, is operates 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, neutron radiography, and neutron beam 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 x 10^{13} n/cm^2/second at the edge of the core to approximately 3 x 10^{13} n/cm^2/second in the central region of the core.

When using the pulse mode of operation, the peak flux for a maximum pulse is approximately 6 x 10^{16} n/cm^2/ second with a pulse width of 15 milliseconds at half maximum.

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

STATISTICAL ANALYSIS

Tables 3 and 4 list Reactor Operation Data and Reactor Utilization Data-Shift Averages, respectively, for the past three years. In Table 3, 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 4, 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.

Table 4, Part B gives a breakdown of the Type of Usage in Hours. The Department of Mechanical and Nuclear Engineering 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.

Table 4, Part C statistics, Users/Experimenters, reflects the number of users, samples and sample hours per shift.

Table 4, Part D shows the number of eight hour shifts for each year.

INSPECTIONS AND AUDITS

On November 2-3, 2003, 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 Bob Agasie, Director, Nuclear Reactor Laboratory, University of Wisconsin-Madison. The reactor staff implemented changes suggested by that report, all of which exceed NRC requirements.

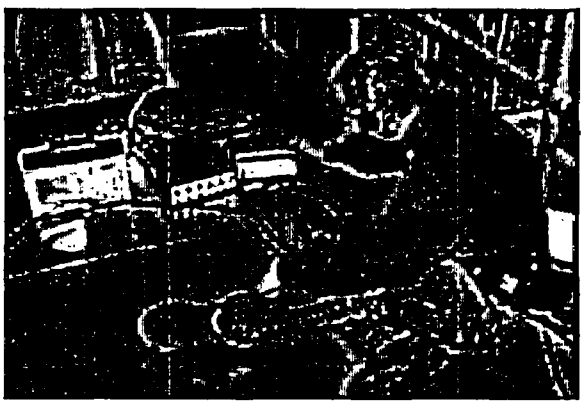


Figure 2. Thierry Daubenspeck, senior reactor operator, assists in performing a calibration procedure.

TABLE 3

Reactor Operation Data
July 2001 – June 2004

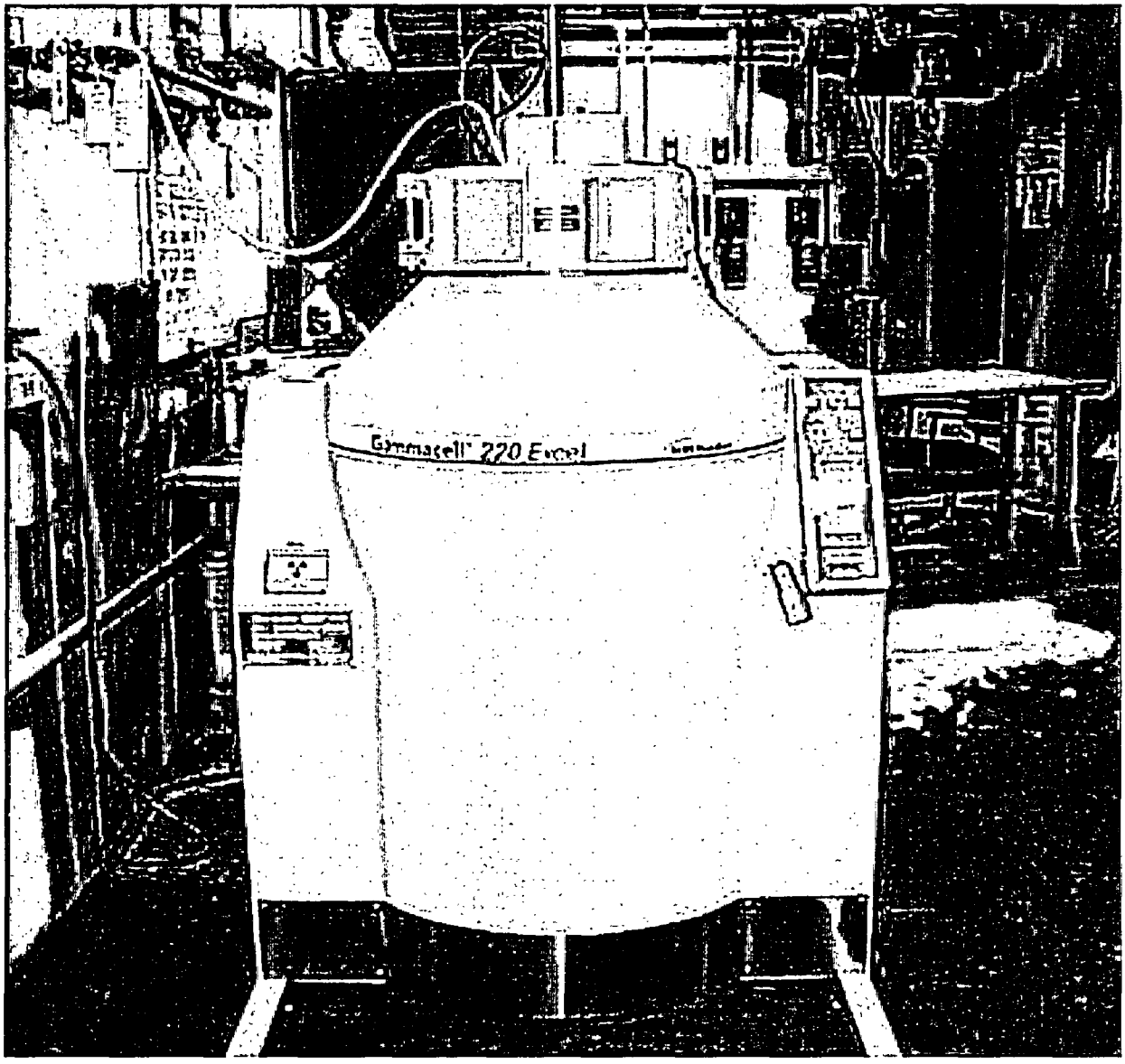
		01-02	02-03	03-04
A.	Hours of Reactor Operation			
	1. Critical	1028	745	1070
	2. Subcritical	424	414	417
	3. Fuel Movement	40	0	6
B.	Number of Pulses	124	125	116
C.	Number of Square Waves	52	59	62
D.	Energy Releases (MWH)	648	458	736
E.	Grams U-235 Consumed	33	24	38
F.	Scrams			
	1. Planned as Part of Experiments	9	16	1
	2. Unplanned – Resulting From:			
	a) Personnel Action	1	0	1
	b) Abnormal System Operation	2	2	2

TABLE 4

Reactor Operation Data
July 2001 – June 2004

		01-02	02-03	03-04
A.	Reactor Usage			
	1. Hours Critical	3.8	2.9	3.9
	2. Hours Subcritical	1.6	1.6	1.5
	3. Hours Shutdown	2	2.1	2.4
	4. Reactor Not Available	0.2	0.2	0.1
	TOTAL HOURS PER SHIFT	7.5	6.8	7.9
B.	Type of Usage – Hours			
	1. Industrial Research and Service	3.5	3.0	3.5
	2. University Research and Service	1.3	0.8	1.4
	3. Instruction and Training	1.3	1.6	1.9
	4. Calibration and Maintenance	1.3	1.4	1.1
	5. Fuel Handling	0.1	0	0
C.	Users/Experiments			
	1. Number of Users	3.1	2.9	3.2
	2. Pneumatic Transfer Samples	1.6	0.2	0.1
	3. Total Number of Samples	4.6	3.2	3.5
	4. Sample Hours	3.4	2.5	3.5
D.	Number of 8 Hour Shifts	271	255	273

GAMMA IRRADIATION FACILITY



GAMMA IRRADIATION FACILITY

The Gamma Irradiation Facility includes in-pool irradiators and a dry-shielded GammaCell 220 Excel irradiator. This provides a great deal of flexibility for dose rates and irradiation configurations.

IN-POOL IRRADIATORS

For the in-pool irradiators, the source rods are stored and used in a pool that is 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 the 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 to 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 the 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.

In March 1965, the University 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 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 5. The dose rates listed for the pool irradiator tubes reflect a new source configuration as of June 30, 2003, which increased the number of sources around the 6-inch tube.

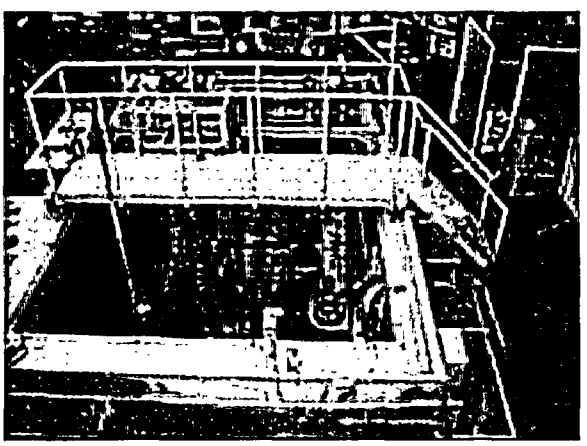


Figure 1. In-Pool Irradiation Facility

GAMMACELL 220 EXCEL DRY IRRADIATOR

The GammaCell 220 Excel dry irradiator was acquired in July 2003 through funding from the U.S. Department of Energy INIE grant. The new irradiator is located in the back area of the Hot Cell Laboratory. This irradiator replaced the old GammaCell 220 Irradiator which was housed in the same room as the pool irradiator. The new irradiator has a dose rate that is considerably higher (by a factor of 10) than the old Gammacell 220 irradiator. Other advantages of the GammaCell 220 Excel include a large irradiation chamber (approximately 6 inches in 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 only disadvantage is the decay heat from the higher dose rate, which increased the temperature of the irradiation chamber. The maximum dose rate is summarized in Table 5.

Figures 2 & 3. GammaCell 220 Excel Dry Irradiator being moved into the Hot Cell Laboratory.

USE OF GAMMA IRRADIATION SERVICES

The use of the Gamma Irradiation facility has been increasing steadily. The number of the sample hours performed in the GammaCell 220 Excel was lower compared to last year due to the higher dose rate. More than 14,000 hours of "equivalent irradiation time" would have been needed if the old GammaCell 220 would have been used - this exceeds the number of hours in a year! The utilization of the Gammacell 220 Excel was only at 16 percent capacity and we achieved more irradiations and irradiated for shorter times. 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. Other University and pre-college educational institutions utilized the gamma irradiation facility through research projects, INIE minigrant projects or the Reactor Sharing program. This information is outlined in the Research and Service utilization section and in Appendix A. Table 6 compares the past three years' utilization of the Cobalt-60 Irradiation Facility in terms of irradiation time and number of irradiations.

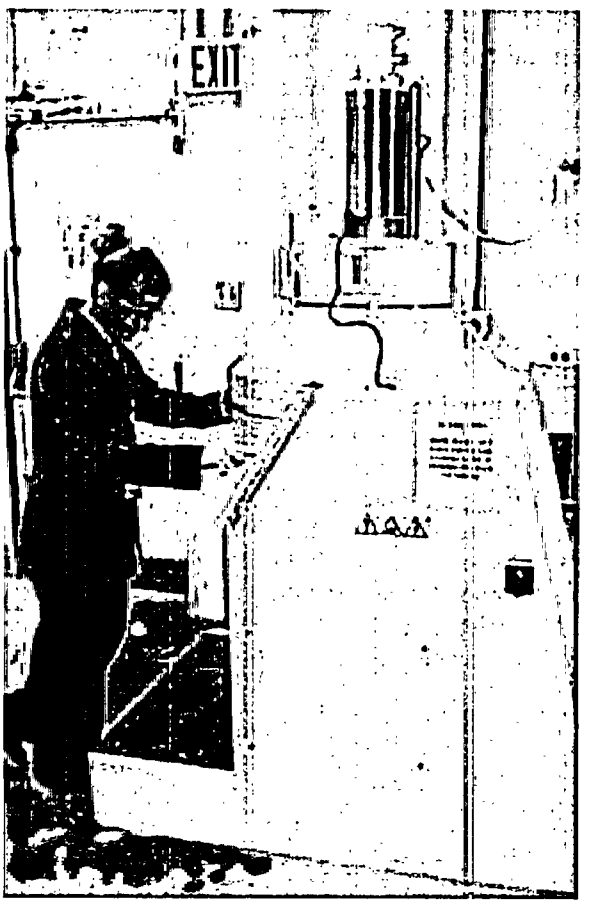


Figure 4. Rachel Slaybaugh, Reactor Operator Intern, inserts a sample into the GammaCell 220 Dry Irradiator.

TABLE 5

Summary of Current Gamma Irradiation Facilities *as of 7/1/2004		
Facility	**Maximum Dose Rate in KRads/hour***	**Sample Limitations**
North Tube 6-inch	33	Must be less than 6 inches in diameter
South Tube 3-inch	25	Must be less than 3 inches in diameter
10-inch Chamber	depends on source array	Cylinder approx. 10 inches in diameter by 12 inches in height
GammaCell 220 Excel Dry Cell Irradiator	1723	Cylinder approx. 6 inches in Diameter by 7.5 inches in height

TABLE 6

Cobalt-60 Utilization Data
July 1 2001 – June 30, 2004

		01-02 Pool Irradiator	01-02 GammaCell 220	02-03 Pool Irradiator	02-03 GammaCell 220	03-04 Pool Irradiator	03-04 GammaCell 220
A.	Time Involved (Hours)						
	1. Set-Up/Admin. Time	17	89	16	71	19	85
	2. Total Sample Hours	394	5667	1835	7352	1086.5	1423[2]
B.	Numbers Involved						
	1. Total Irradiations	33	227	84	223	50	249
	2. Samples Containers Run[1]	204	1200	958	959	294	1379
	3. Different Experimenters	5	29	11	25	11	39
	4. Configurations Used	4	N/A	4	N/A	4	N/A

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

[2] Note the sample hours for the GammaCell 220 Excel would be equivalent to over 14,000 sample hours in the old GammaCell 220.

FIGURE 2

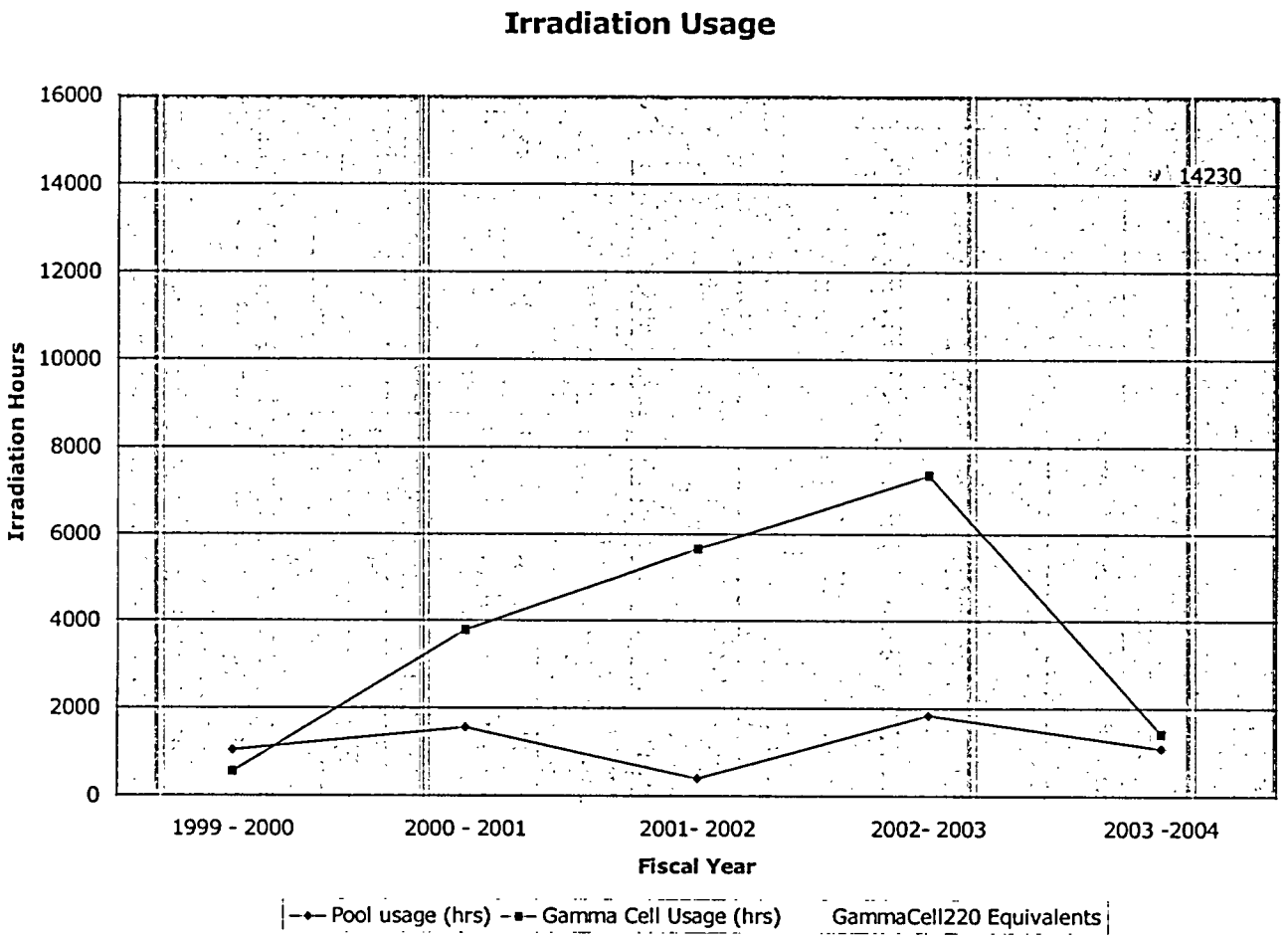

Irradiation Usage
16000
14000
12000
10000
8000
6000
4000
2000
0
Irradiation Hours
14230
1999 - 2000
2000 - 2001
2001- 2002
2002- 2003
2003 -2004
Fiscal Year
Pool usage (hrs)
Gamma Cell Usage (hrs)
GammaCell220 Equivalents

FIGURE 3

Gamma Irradiation Uses and Examples

Genetic Changes

Poinsettias

Fruit Flies

Class Projects and Demonstrations:

Beef Patties

Table Salt

Bean Seeds

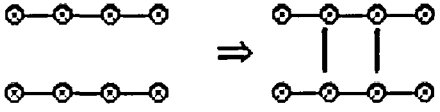
Glass Jars

Mushrooms

Sterilization
Medical & Laboratory Products

Water

Cross-Linking of Polymers



Soil & Leaves for Environmental Research

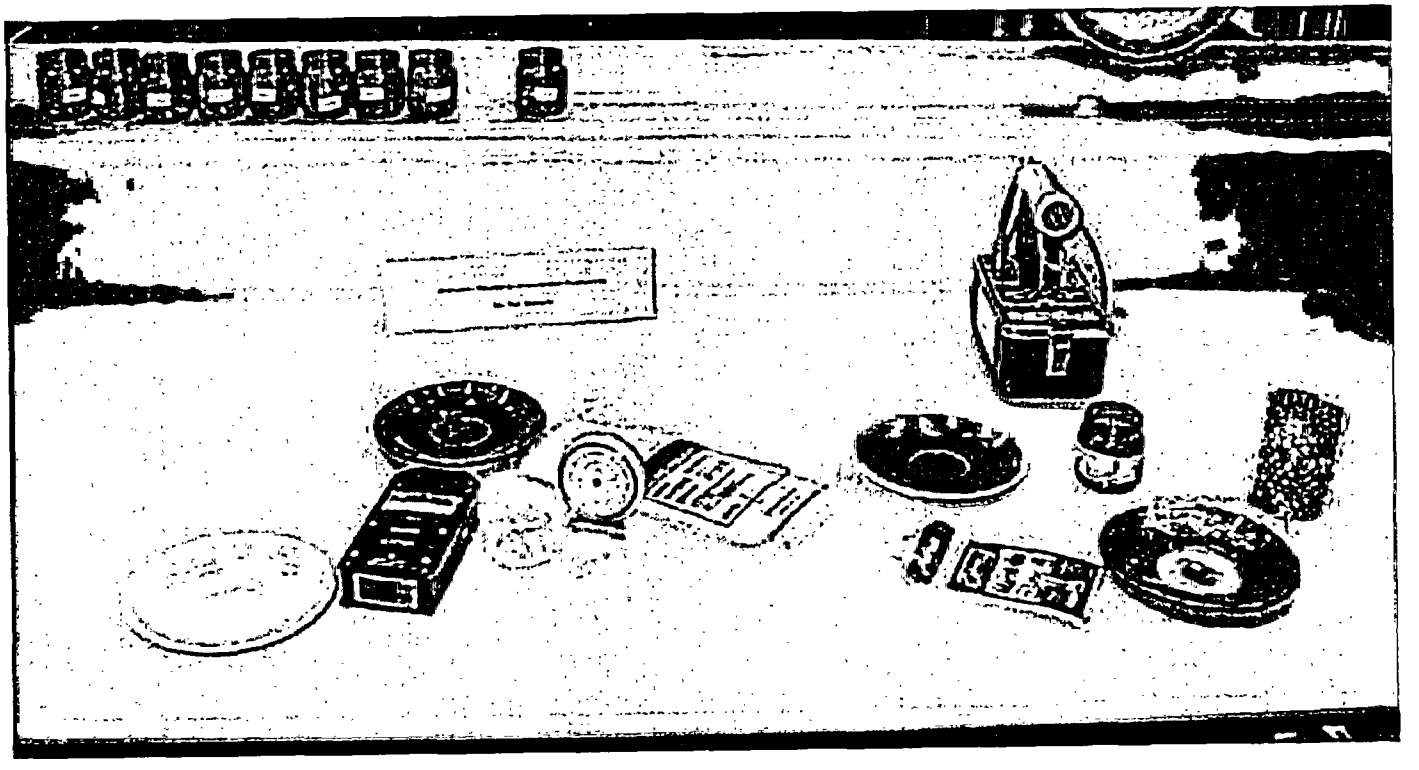
Carnations

Food Irradiation

Strawberries

Bread

EDUCATION AND TRAINING



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

Facility staff and ANS student members have participated in activities for the Boy Scouts of American and the Girl Scouts of the United States of America. Facility staff and students provided input into the development of a revised nuclear science merit badge to replace the atomic energy merit badge booklet. Students and staff also provided suggestions for the requirements of a nuclear science interest patch for Girl Scouts. The student ANS members conduct programs for scouts at the facility. Twenty-six Girl Scouts participated in activities to earn the nuclear science interest patch sponsored by the Penn State Student ANS chapter. A short report on the Girl Scout program is included.

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.

U.S. DEPARTMENT OF ENERGY – INIE MINIGRANT

Several educational institutions participated in mini-grant projects at the RSEC facility through the INIE minigrant process. The following is a synopsis of the institutions that participated in educational outreach and educational research projects utilizing the Penn State Reactor Facility. All of the participants traveled to the reactor facility to learn about nuclear applications and understand some of the procedures and equipment utilized in the projects. The Central Virginia Governor's School conducted a neutron radiography experiment and utilized the gamma irradiation capabilities. Neutron irradiation and neutron activation analysis were discussed, but this presented a problem in conducting projects due to the production of radioactive materials. Two secondary science teachers, Guy Anderson from Bald Eagle Area High School and Dwight Johnston from Spring Grove Area High School conducted projects to assist in improving their nuclear science curriculum. High school student Katherine Ann Colburn collected water samples at different locations and used NAA for analysis of the samples. Candace Davison of the Penn State Reactor Facility worked with a group of pre-college science teachers to develop an equipment loan program for teaching nuclear science. Guy Anderson, a local teacher utilized the equipment to improve the ratio of students to equipment thus providing a better learning experience for his students.

NUCLEAR SCIENCE & TECHNOLOGY COURSE

A one-week course on Nuclear Science and Technology was conducted from July 15-19, 2003. John Vincenti was the coordinator of the course, which was held, again based upon the success of the previous course. Fourteen teachers attended the workshop and received free Geiger Counters through a grant from the American Nuclear Society and U.S. Department of Energy. Candace Davison provided instruction on radiation, reactor basics, nuclear applications and conducted experiments at the facility for the participants.

TOURS

In addition to the full or half-day programs with experiments, educational tours were conducted for students, teachers, and the general public. All groups, including those detailed in the above sections, which toured the facility are listed in Appendix B. The RSEC operating staff along with the mechanical and nuclear engineering department conducted several open house events for the Parent and Family Weekend, the general public and potential undergraduate or graduate students. Over 300 people participated in Open House and "Spend a Day" experiences.

Figure 1. A school tour group looks over displays in the Reactor Bay.

ACADEMIC INSTRUCTION

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

The joint instructional experience for students in the IE 408W (Human Factors) course was continued in the fall semester. The students were instructed on reactor basics so that they could understand the control signals and input along with an overview of the control console in the classroom. The students then went into the control room where they observed a start-up and the operator's actions. They also observed the reactor while at power. Feedback from the students was very positive concerning their real-world experience.

The reactor classroom was utilized as the base of instruction for several courses including; Freshman Seminar (Fall 2003 and Spring 2004), NucE 444, NucE 450, and NucE 451. The TRIGA reactor and Cobalt-60 irradiation facilities were used by several nuclear engineering courses and courses in other departments of the university as outlined in the table below.

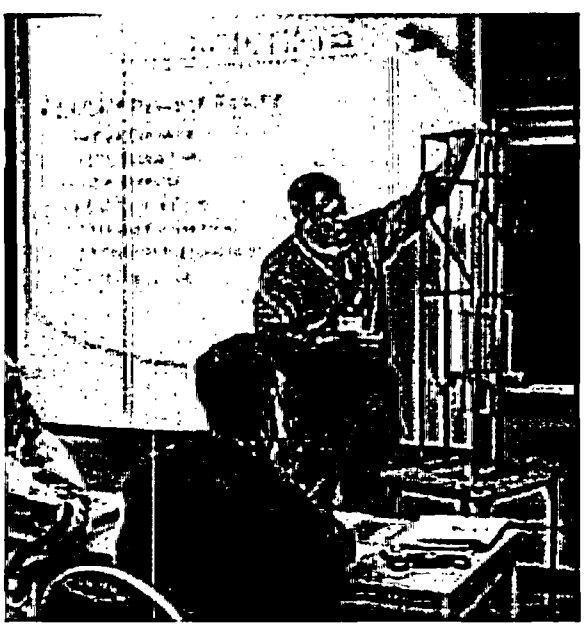


Figure 2. Brenden Heidrich, research assistant, demonstrates ejection of the Transient Rod during a Reactor pulse to Freshman Seminar.

Figure 3. Fred Sears, director RSEC, teaches the Reactor Operations course, NucE 444.

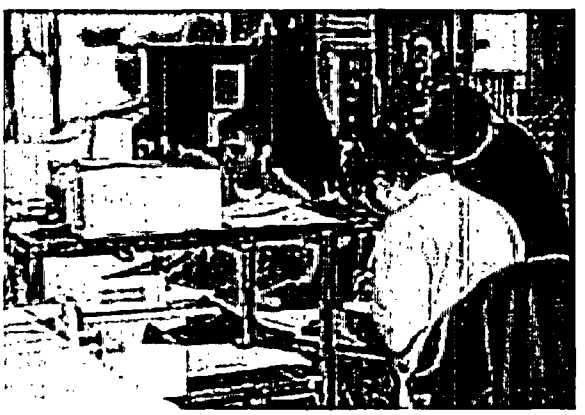


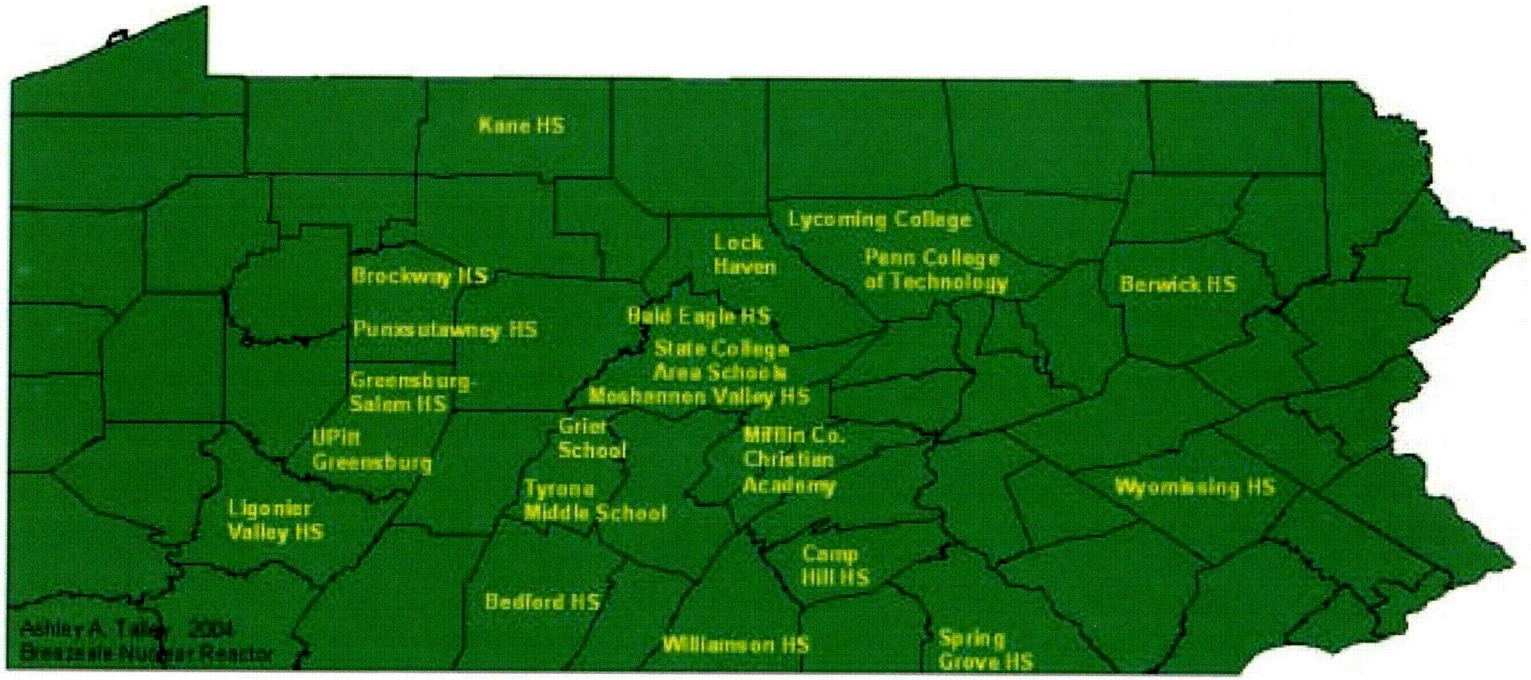
Figure 4. NucE 451 students participate in a laboratory session utilizing the Breazeale Reactor Facility.

TABLE 7

Semester	Course	Instructor	Students	Hours
Summer 2003	SCIED 498B – Nuclear Science and Technology Workshop	J. R. Vincenti C. C. Davison	10	6
Fall 2003	NUCE 001S – Freshman Seminar	J. S. Brenizer	37	14
Fall 2003	Nuc E 301 – Fundamentals of Reactor Physics	R.M. Edwards	28	2
Fall 2003	Nuc E 310W – Issues in Nuclear Engineering	A. Motta	2	1
Fall 2003	Nuc E 401 – Introduction to Nuclear Engineering	L. Hochreiter	6	5
Fall 2003	Nuc E 451 – Experimental Reactor Physics	R.M. Edwards	21	20
Fall 2003	Nuc E 444 – Nuclear Reactor Operations	C. F. Sears	4	45
Fall 2003	ENGR 100S - Freshman Seminar	A. Motta	13	1
Fall 2003	Food Science 413 – Science & Technology of Plant Food	R. B. Beelman	13	3
Fall 2003	IE 408 W-Human Factors	L. Newman	63	6
Fall 2003	ME 33	G. Talmage	28	7
Spring 2004	NUCE 001S – Freshman Seminar	J. S. Brenizer	9	14
Spring 2004	Nuc E 444 – Nuclear Reactor Operations	C. F. Sears	5	90
Spring 2004	Nuc E 450 – Radiation Detection and Measurement	R.M. Edwards	13	6
Spring 2004	ME 30H	D. A. Santavicca	4	1
Spring 2004	CHEM 036 (Penn State Altoona)	C.S. Reed	8	2

FIGURE 4

Educational Institutions Visiting the RSEC

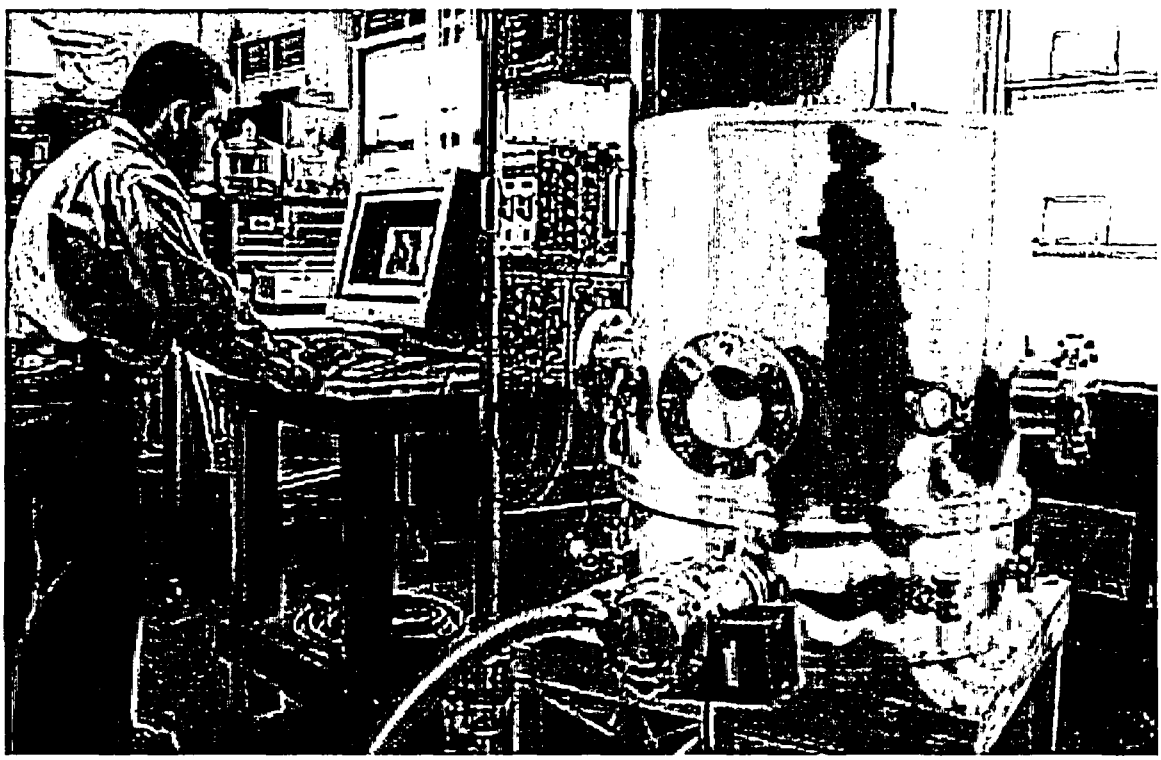


■ Davison Middle School, North Carolina

Bettinenn High School, Louisanna

C01

NEUTRON BEAM LABORATORY



NEUTRON BEAM LABORATORY

The Neutron Beam Laboratory (NBL) is one of the experimental facilities at the RSEC. Well-collimated beams of neutrons, thermalized by a D_2O tank, are passed into the NBL for use in various neutron beam techniques. When the reactor core is placed next to a D_2O tank and graphite reflector assembly near the beam port locations, thermal neutron beams become available for neutron transmission and neutron radiography measurement from two of the seven existing beam ports. In steady state operation at 1 MW, the thermal neutron flux is $1x10^{13}$ n/cm^{2}sec at the edge of the core and $3x10^{13}$ n/cm^{2}sec at the central thimble. The Penn State Breazeale Reactor (PSBR) can also pulse with the peak flux for maximum pulse ~ $6x10^{16}$ n/cm^{2}sec with a pulse width of 15 msec at half maximum.

CURRENT STATUS OF PSBR BEAM PORTS

The PSBR has seven beam ports. The internal diameter of the beam ports are four inches for BP #3 and BP #5; five inches for BP #1 and BP #7; and six inches for BP #2, BP #4 and BP #6. The center of BP #4 is 65 inches from the pool floor while BP #1, BP #3, BP #5 and BP #7 are 60 inches and BP #2 and BP #6 are 54 inches from the pool floor. With the current setup of reactor-core-moderator assembly only BP #4 is at the centerline of the TRIGA core. (Active length of TRIGA fuel is 15"). BP #1, 3, 5 and 7 are five inches below the centerline of the core and BP #2 and 6 are eleven inches below the centerline of the core. The core grid assembly does not permit lowering the core more than the current arrangement. When the PSBR reactor was built, MTR type fuel elements with active length of 24" were used. With the MTR fuel the beam port arrangement did not limit the maximum neutron output. In the mid 60's the PSBR was converted from MTR type to TRIGA type fuel. With TRIGA fuel, only one beam port is at the centerline of the core active area, four beam ports are five inches below the centerline and two are eleven inches below the centerline (below the active fuel region). Because of these inherited limitations only two beam ports are currently being used. BP #4 with 3 x 10^7 n/cm^{2}sec flux at the aperture is used for research, primarily neutron radiography and radioscopy, and BP #7 with ~ 10^5 n/cm^{2}sec neutron flux is used for service activities involving neutron transmission measurements. Since the BP #4 collimators are primarily designed and optimized for neutron radiography and radioscopy measurements, it is not possible to obtain desired results for other measurements. We are currently trying to use BP #4 for all of our research projects. Due to space limitations, we must shuffle delicate research equipment around. More importantly, each project or experimental techniques require a special or dedicated neutron beam with different collimations and neutron flux.

NEW BEAM PORTS AND BEAM HALL EXPANSION

Due to inherited design issues with the current arrangement of beam ports and reactor core-moderator assembly, the development of innovative experimental facilities utilizing neutron beams is extremely limited. Therefore, a new core-moderator location in PSBR pool and beam port geometry needs to be determined in order to build useful neutron beam facilities. A study is continuing with the support of DOE-INIE funds to examine the existing beam ports for neutron output and to investigate new core and moderator designs that would be accessible by additional beam ports. We envision a location in the pool where reactor core would be "parked" and surrounded by a moderator (D_2O or graphite). New beam ports would be geometrically aligned with the core-moderator assembly for optimum neutron output.

The new core-moderator and beam port arrangement requires expansion of the existing beam laboratory in order to place instrumentation, neutron guides, and beam catcher, etc. The new beam hall will have a total of 3,700 sq ft of experimental area (the existing area of ~1,000 sq ft plus a new additional area of ~2,700 sq ft). Also, about 3,100 sq ft of new office and meeting/classroom space will be added in the second floor of the expanded beam hall to support students and faculty working in this area.

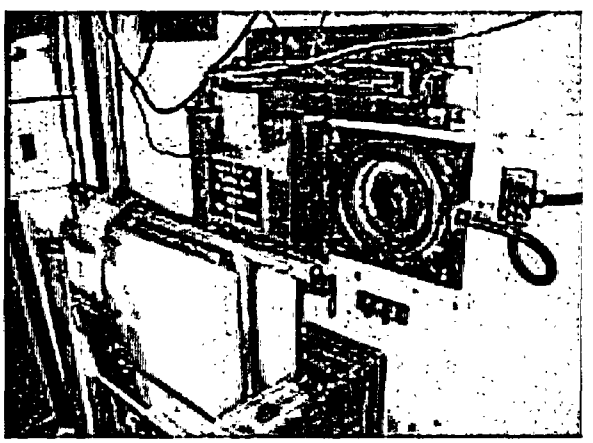


Figure 1. A picture of BP #4 collimator aperture and testing rig of a semiconductor memory chip.

Architectural plans for the RSEC expansion for a new Neutron Beam Hall and Neutron Beam Ports facilities are completed. Working with a professional architectural firm, a contractor, and related personnel from various university functions, we obtained a firm estimate for the expansion cost. Internal benefactors of the new neutron beam facilities are identified. We obtained support letters or expression of interests from about 30 faculty members from four different colleges within the university. More than half of the total budget for expansion is currently available, and efforts to raise the remaining portion of budget continue.

Research areas envisioned for RSEC's new beam port/ beam hall design are as follows. Neutron Depth Profiling facility for depth vs. concentration measurements, impurity determination of He-3 and B-10 in semiconductors, metal and alloys; Cold Neutron Source and Cold Neutron Prompt Gamma Activation Analysis for neutron focusing research, materials characterization and determination of impurities in historically or technologically important material; Neutron Powder Diffraction for structural determination of materials, and a Triple Axis Diffractometer to train students on neutron diffraction and perform preliminary structural determinations of materials.

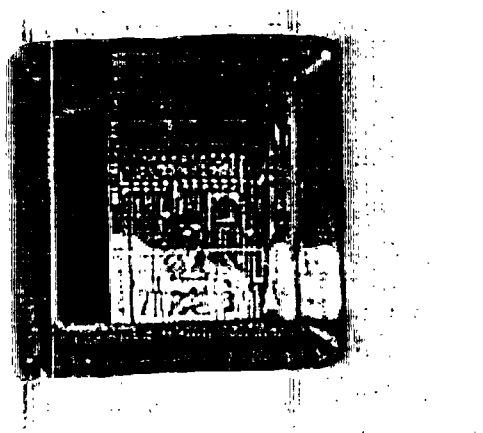
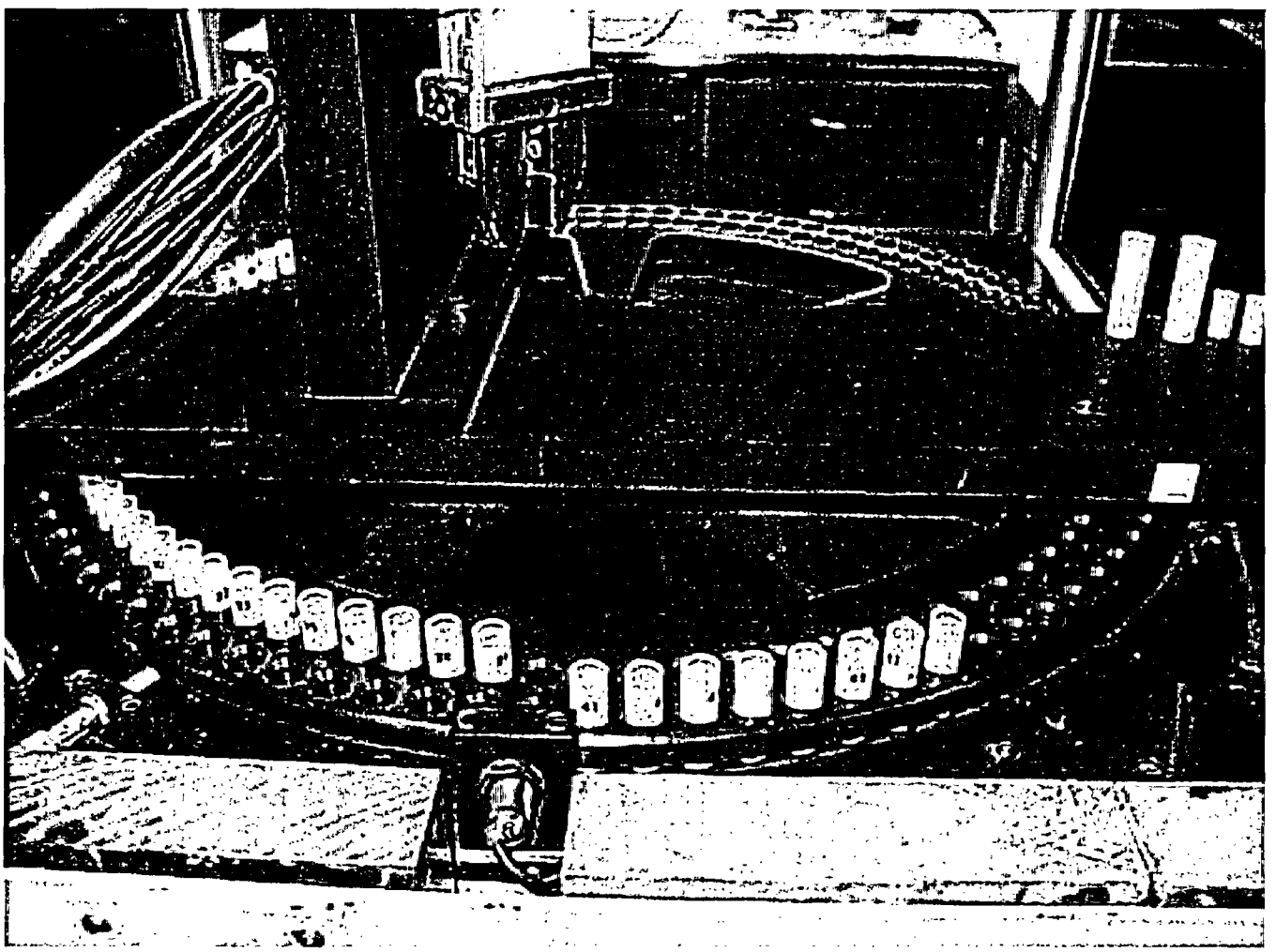


Figure 2. A picture of a semiconductor memory chip through an aperture at a polyethlene/lead shielding fixture.

Projects utilizing the NBL during the year included the following:

- Time-of-Flight Neutron Depth Profiling at the Penn State University Breazeale Nuclear Reactor (see Research and Service Utilization Section, page 73).
- Neutron Beam Characterization of the Breazeale Nuclear Reactor at Penn State, Radiation Science and Engineering Center (see Research and Service Utilization Section, page 62).
- Testing Neutron-Induced Soft Errors in Semiconductor Memories (see Research and Service Utilization Section, page 65).
- Soft Error Analysis Toolset (SEAT) Development (see Research and Service Utilization Section, page 51).
- Study of Water Distribution and Transport in a Polymer Electrolyte Fuel Cell Using Neutron Imaging (see Research and Service Utilization Section, page 44).
- Neutron Imaging System Improvements (see Research and Service Utilization Section, page 57).
- Modelling of existing beam-port facility at Penn State Breazeale Nuclear Reactor by using MCNP (see Research and Service Utilization Section, page 81).
- Investigation of preferential flow of water in sand samples using real time neutron radiography. Collaborative work with Cornell University, Ward Center for Nuclear Sciences.
- Neutron transmission measurements and neutron radioscopy were conducted for borated metals and other borated materials for numerous companies.
- 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 and students enrolled in the freshman seminar (NucE 001S). The students assembled plaques containing a variety of objects and predicted their neutron & x-ray attenuation characteristics. Experiments with neutron & x-ray radiography confirmed their predictions.

RADIONUCLEAR APPLICATIONS LABORATORY



A. Service
B. Research

RADIONUCLEAR APPLICATIONS LABORATORY
Section A. Service

The Radionuclear Applications Laboratory (RAL) provides consulting and technical assistance to personnel wishing to use radionuclear techniques in their research projects. The majority of these projects involve neutron activation; however, the staff is also able to provide services in radioactive tracer techniques, radiation gauging, and isotope production for laboratory, radionuclear medicine or industrial use. RAL personnel support daily RSEC operations by performing analyses of water, air monitor filters, and other samples as needed to meet regulatory requirements.

During the past fiscal year, a total of 444 semiconductor irradiations were performed for nine different companies. The devices were prepared for irradiation in accordance with accepted procedures. Afterwards, the 1-MeV Silicon Equivalent fluence was calculated from the flux monitors irradiated with the devices. The irradiated devices were analyzed to determine the radioisotopes present for shipping and licensing requirements. RAL personnel returned irradiated devices in accordance with NRC and DOT regulations.

RAL personnel performed a total of 18 isotope production runs of Sodium-24, Bromine-82 and Argon-41 for industrial use during the past fiscal year. If necessary, personnel are 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. Irradiations and analytical work were performed for graduate and undergraduate students in the nuclear engineering and the anthropology programs. Nuclear engineering students use the RAL for various projects 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 is an on-going project that began years ago.

Figure 1. Thierry Daubenspeck, activation and utilization specialist/senior reactor operator explains Pneumatic Transfer system to students from the University of Pittsburgh.

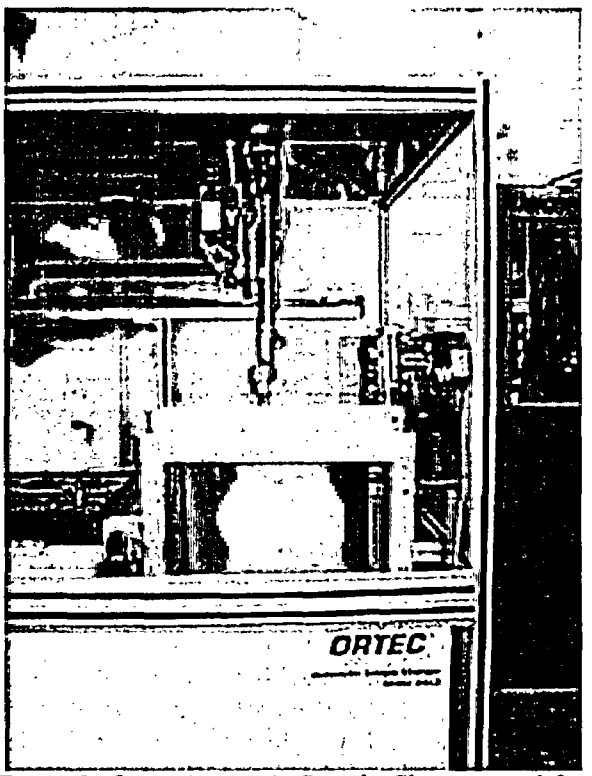


Figure 2. Ortec Automatic Sample Changer used for long-lived isotopes.

In the past year, the Instrumental Neutron Activation Analysis (INAA) facility was completed at the Breazeale Nuclear Reactor. This includes installing two Dry Irradiation Tubes (DT) in the reactor core, getting the Automatic Sample Handling System (ASHS) up and running, setting up the analysis system with a High-Purity Germanium (HpGe) Detector, a Digital Spectrum Analyzer and Genie-2000 software, and doing the flux measurements necessary to identify flux peak area for sample irradiation positions. A close-up picture of ASHS showing the sample tray and robot arm is given below. A compton suppression system is being purchased with INIE funds in order to make more in-depth analysis of some samples using NAA. Also, Room 4 is being converted to a NAA sample preparation facility.

Figure 3. Graduate student Danielle Hauck gathers her samples from the sample changer.

The current main activity at RAL is a dendrochronology project. The objective of this study is to determine experimentally periods of global environmental stress during the past six thousand years using tree samples already collected and dated and neutron activation analysis (NAA). The result of this study will provide climate modelers with a much needed extended timeline. This study is the first coordinated dendrochemical study of a period longer than one hundred years, and the first study in the archaeologically important eastern Mediterranean. The Malcolm and Carolyn Wiener Laboratory for Aegean and Near Eastern Dendrochronology at Cornell University, archives 40,000 individually-dated tree samples with 4.5 million rings from 109 forests in the eastern Mediterranean and former Soviet Union. These samples span most of the period from 7000 BC to the present. All dendrochronologically dated samples at the Wiener Laboratory are available for this study.

Staff and students of the Wiener Laboratory have already prepared approximately three thousand samples of wood for this study. A dedicated NAA system was built at Cornell's Ward Center for Nuclear Sciences. The prepared samples, gamma spectroscopy system, and sample changer were transferred to Penn State's Radiation Science and Engineering Center. Measurements will continue using the 1 MW Breazeale Nuclear Reactor. Please see details of this project in page 69 of this report.

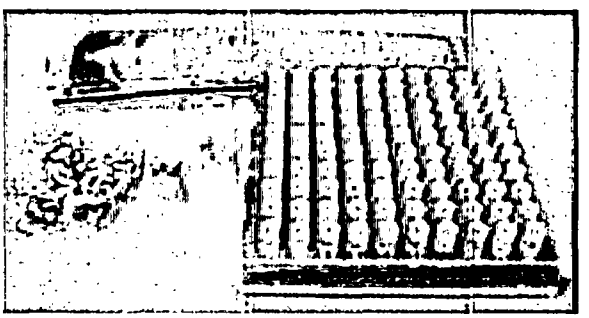


Figure 4. Tree samples.

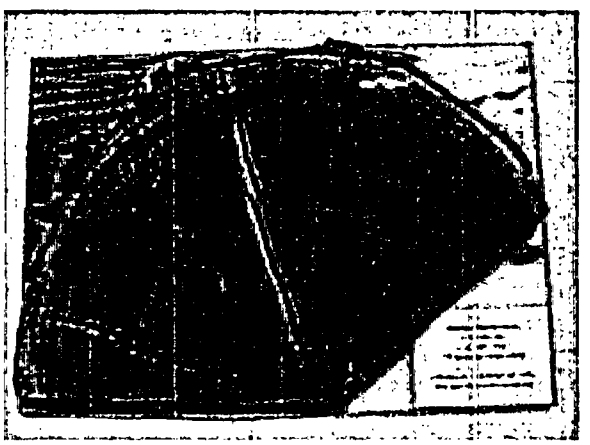
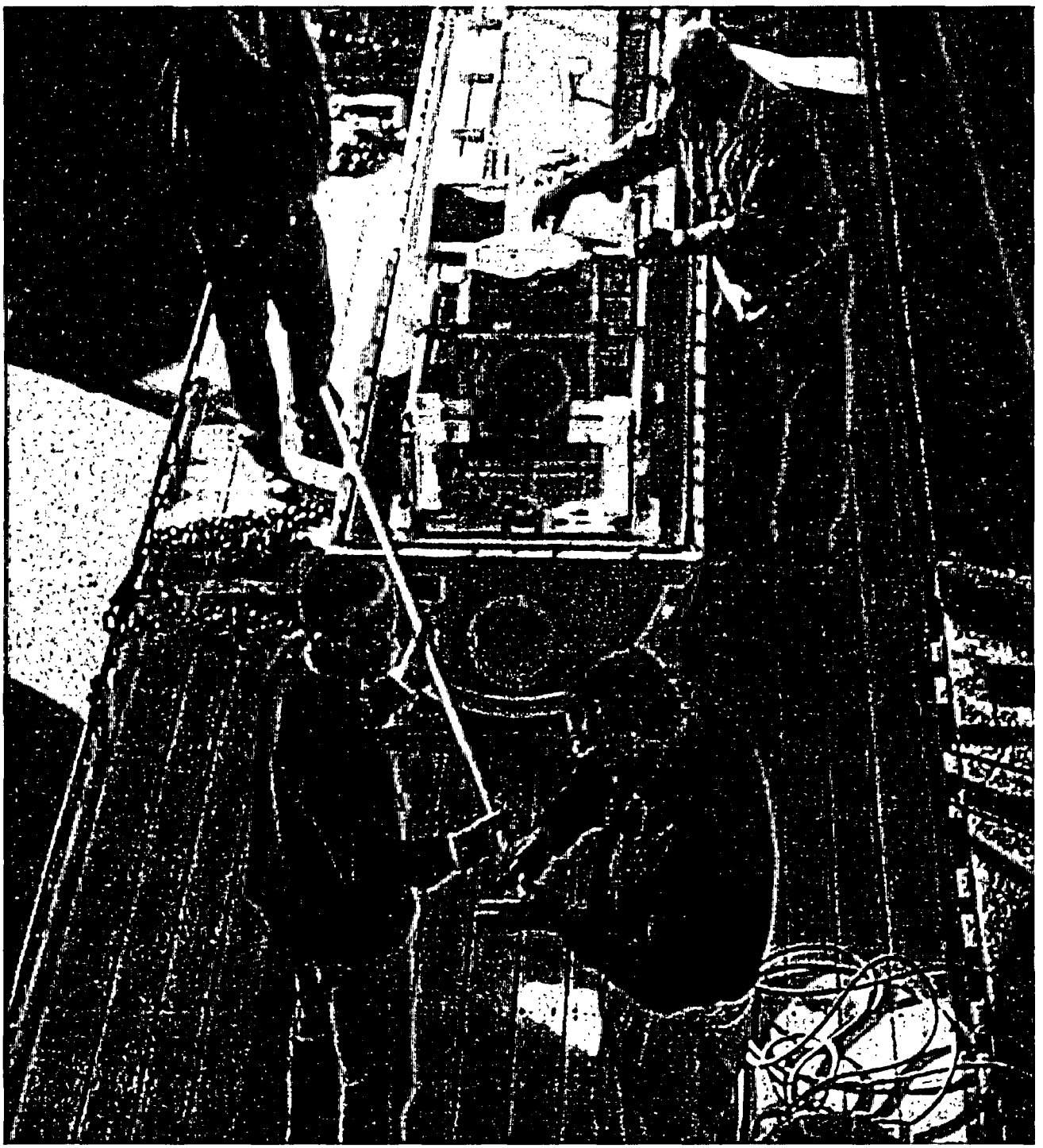


Figure 5. A tree sample from Istanbul, Belgrade Forest. The innermost pin is placed at 1800 A.D., other pins follow at 50-year intervals.

PATHFINDER FUEL SHIPMENT



PATHFINDER FUEL SHIPMENT

INTRODUCTION

During the latter portion of 2003, 417 Pathfinder Fuel assemblies were removed from storage at Penn State and transported to Sandia National Laboratories for utilization and storage. The first transfer of the fuel assemblies occurred on Sep. 9, 2003 and the tenth transfer occurred on Nov. 18, 2003.

BACKGROUND

In October 1969, the Atomic Energy Commission loaned 417 fuel assemblies to Penn State to be used in a subcritical assembly. The subcritical assembly was never built and Penn State requested the uranium be returned to DOE control. The fuel assemblies were stored in a vault. Each fuel assembly was marked with a unique number used to support inventory control and was encased in a 1 inch O.D. sleeve which also had a unique marking. The inventory records showed the storage rack location of each fuel assembly by the unique markings. The assembly ends were free of rust and dirt and in excellent condition. Likewise there was no rust or indications of damage on any of the sleeves that were visually inspected.

PREPARATIONS FOR RETRIEVAL

The project team for the retrieval of the fuel assemblies was made up of representatives from the Department of Energy (DOE), GEM Technologies Inc. (GEM), Penn State and Sandia National Laboratory (SNL).

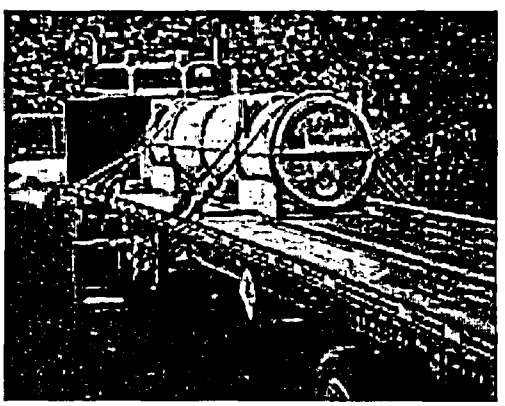


Figure 1. Framatome cask on semi-tractor trailer.

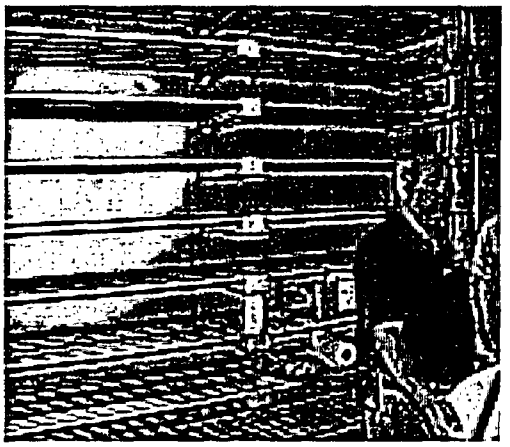


Figure 2. Interior view of the fuel racks in PSU storage room.

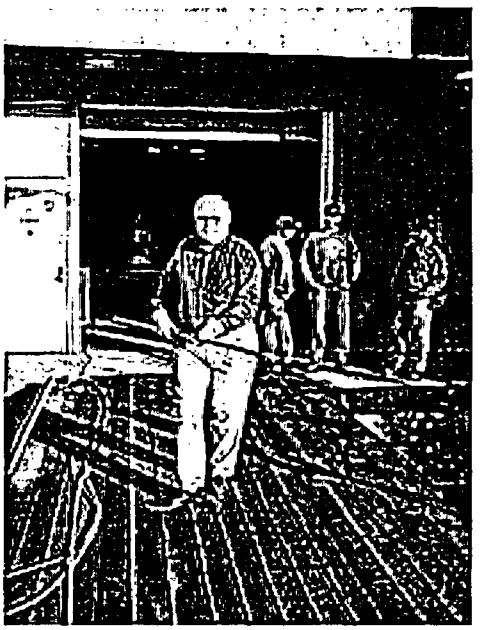


Figure 3. A member of GEM personnel helps to load fuel into the cask.

RETRIEVAL EFFORT

The fuel assemblies were transported from Penn State to SNL in a Framatome commercial nuclear fuel transport cask with an internal liner. The cask was specially modified for use with the Pathfinder fuel, and transported on a semi-tractor trailer. Figure 1 shows the cask and semi-tractor trailer. Penn State provided the instructions for the packing of the fuel assemblies in the WE-1 container and the associated radiological surveys. The Penn State Pathfinder Retrieval Plan provided detailed cask handling instructions and incorporated Framatome procedure: MA-649, Pathfinder Fuel Packaging, Shipping, and Container Storage for the WE-1 Shipping Container. Figure 3 is a view of GEM personnel helping to load fuel into the cask.

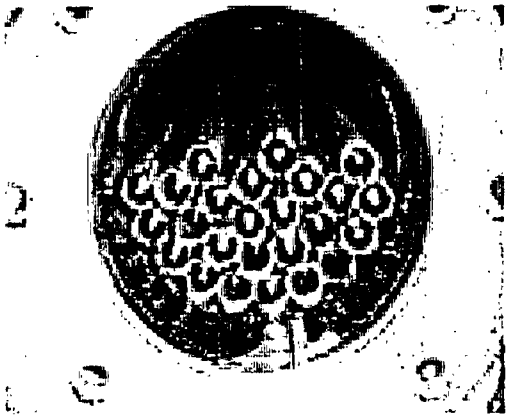


Figure 4. View of the cask partially loaded.

Forty-three fuel pins were loaded into the cask for each trip to the Sandia National Laboratory, with the exception of the tenth and last shipment, where only 30 elements were left.

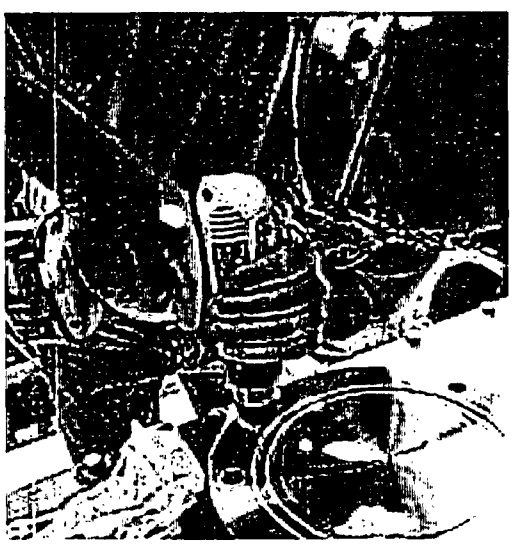


Figure 5. Ron Eaken, Penn State Machinist drills holes in the old O-rings in the cask end plate in preparation for removing them.

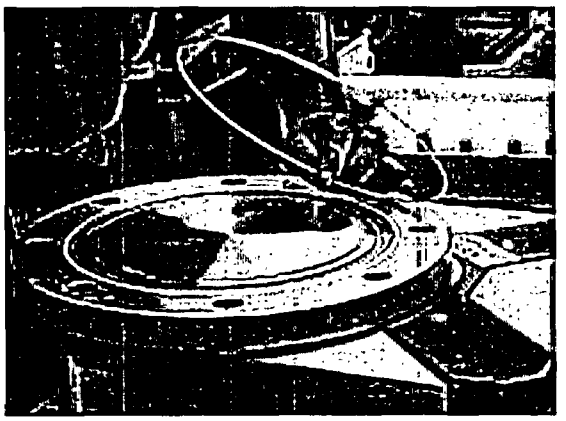


Figure 6. Removal of one of the old O-rings.

Figure 7. Dave Bertocchi of Penn State Radiation Protection performing a neutron survey of the loaded cask.

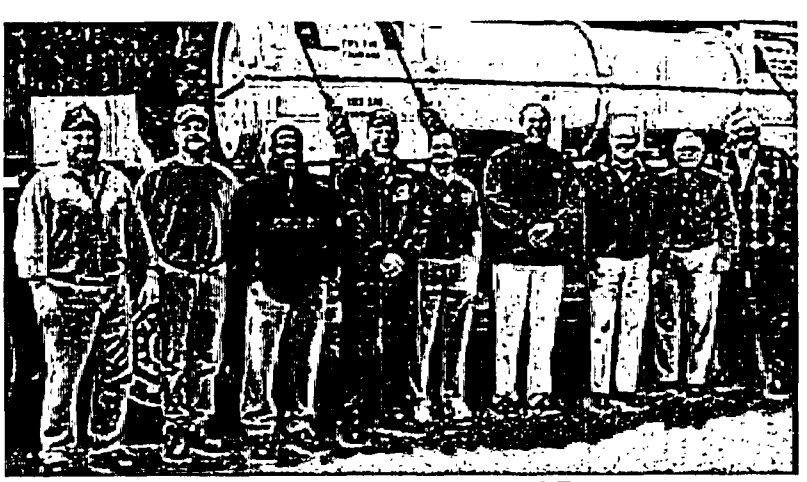
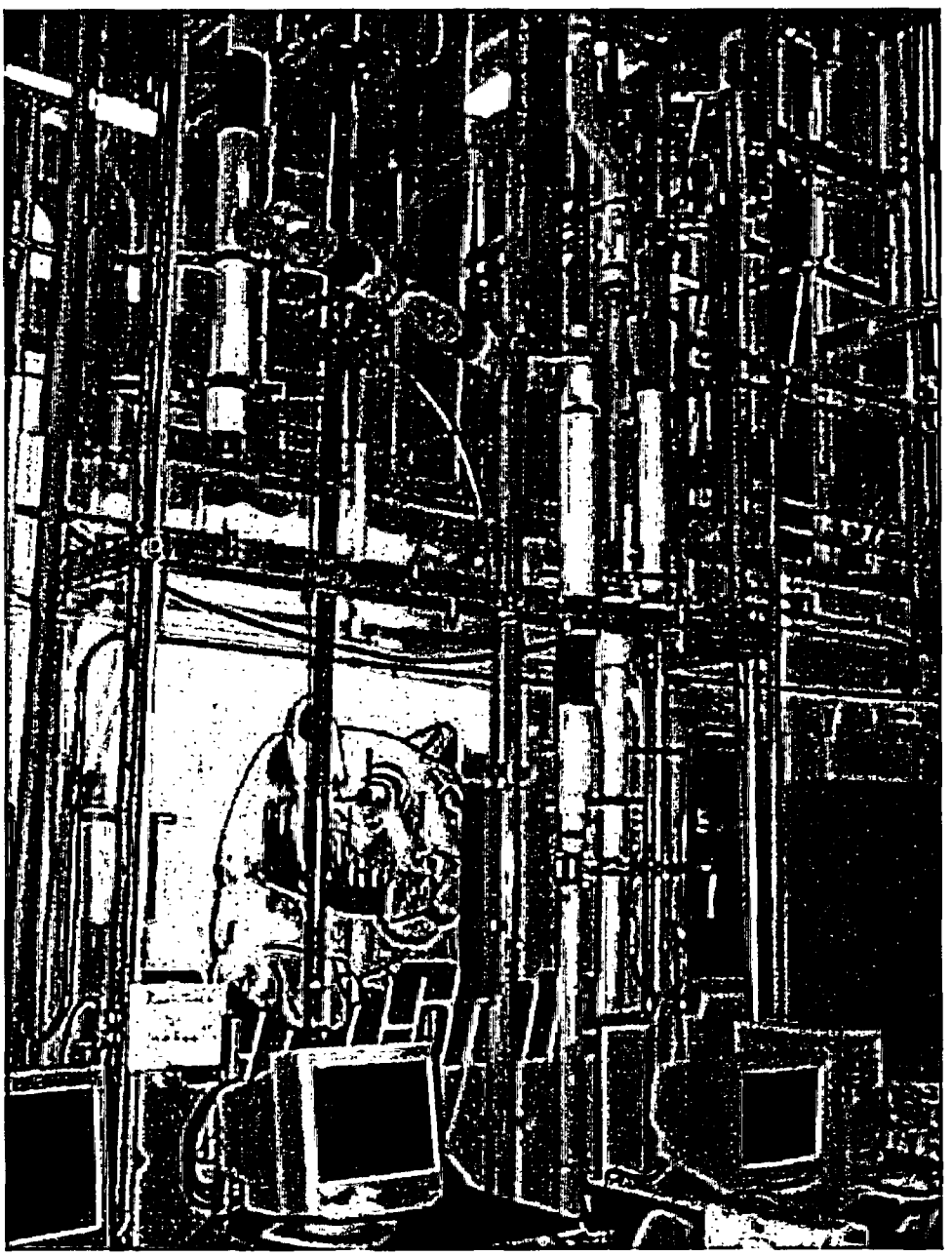


Figure 8. Penn State Uranium Retrieval Team.

LOW PRESSURE INTEGRAL TEST FACILITY



LOW PRESSURE INTEGRAL TEST FACILITY

INTRODUCTION

The Penn State Low-Pressure Integral Test Facility (LPITF) is a one-half height scaled representation of General Electric's Simplified Boiling Water Reactor (SBWR). The unique characteristic of the facility is that it was designed, built, and engineered by Penn State Nuclear Engineering undergraduate students. The facility was started in 1995 with funding from the Dean of Engineering. Subsequent funding was obtained from different companies, such as Westinghouse, Rosemount-Fisher and others as well as matching funds from the Department of Energy. Penn State students participated in the scaling analysis used for the design, the hardware design, and fabrication of the facility components, analysis of the facility response, testing and analysis associated with the data. The facility operates near atmospheric pressures to take advantage of displaying boiling phenomenon at relatively lower temperatures.

The facility underwent a great deal of modification in 2003. The previous facility design had some problems with the two-phase natural (re)circulation. A new design was introduced to overcome some of the problems in flow stability (Figure 1). The new design also incorporates a motor actuated valve to improve the controllability of the loop (Figure 3).

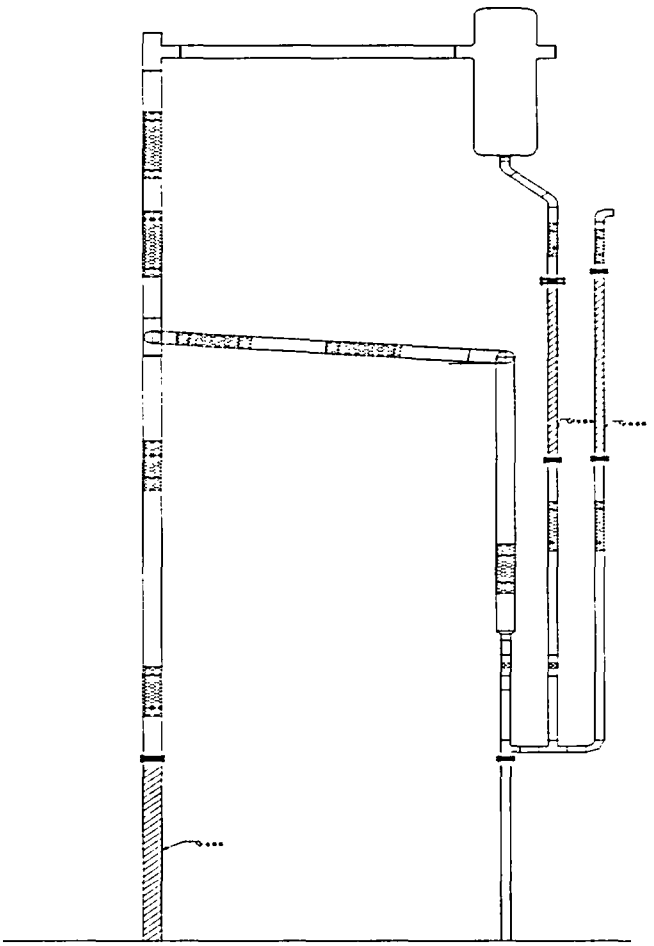


Figure 1 – Detail of the modifications to the downcomer line and crossover leg.

DESCRIPTION OF FACILITY

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

The core and the downcomer regions of the test loop are partially made of borosilicate glass so that the flow can be seen. This configuration allows students to visually study the boiling process and two-phase flow behavior over a range of thermal-hydraulic conditions. Figure 3 shows the front-view of the test loop. To the right is the borosilicate glass core. There are several penetrations on the core section for instrumentation including pressure transducers, void probes, and thermocouples.

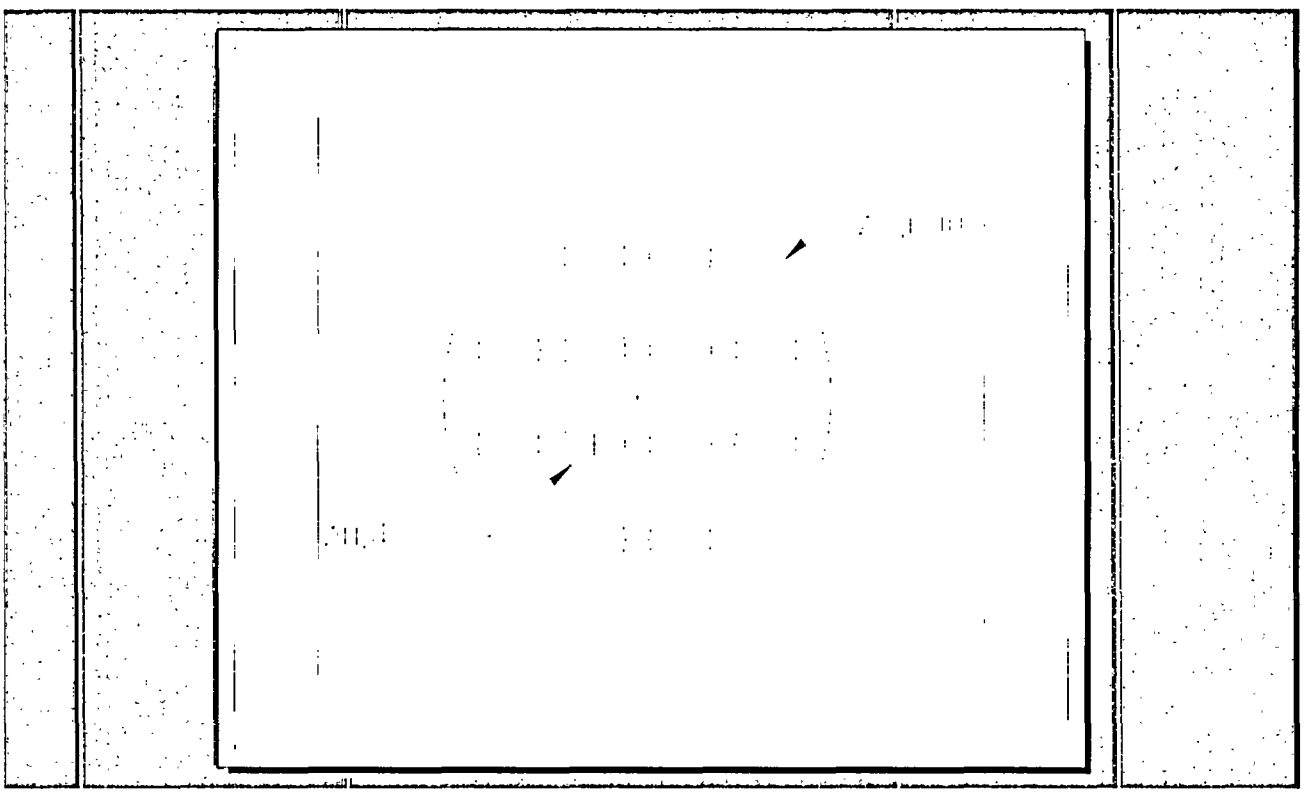


Figure 2 – Core rod layout.

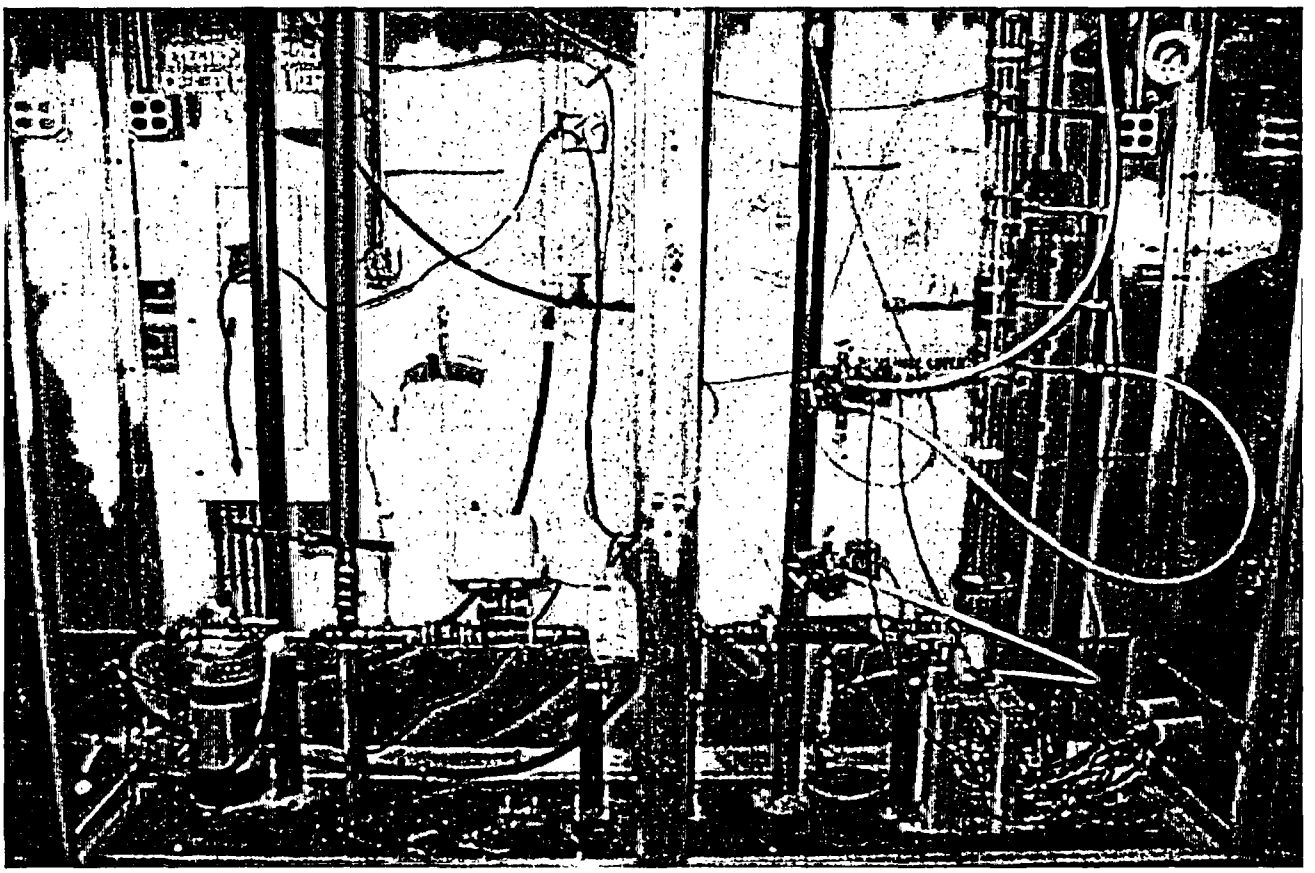


Figure 3 – Front view of the test loop core section. The core is located on the basement of the Cobalt-60 irradiation facility.

MODIFICATIONS AT THE FACILITY

The previous design had stability problems for two-phase (re)circulation experiments. The facility was designed to simulate the basic behavior of SBWR, however drastic differences in operating conditions resulted in major problems in the operation of the facility. First of all, SBWR operates at pretty high pressures relative to the LPITF. Operation at near atmospheric pressures makes the facility vulnerable to gravity, acceleration, and friction pressure drop; because as the water rises in the chimney section, it loses its head resulting in a considerable pressure loss compared to the operating pressure level. This has a significant impact on calculations regarding to two-phase flow. This cannot be resolved by any means other than changing the operating pressure of the facility.

The other problem was flow reversal to the main condenser: Since the two-phase flow experiments did not involve the main condenser in order to reduce water inventory, the portions of the facility above the steam separator were under vacuum. Water at a relatively higher pressure forced water/steam mixture through the condenser return line. Water forced to the condenser got cooled down and turned back to the circulation below saturation temperature resulting in change in temperature distribution along the loop.

The new design employs a three-leg downcomer section, which separates steam separator return line, condenser return line and downcomer line from each other. This way water/steam mixture has a less probability to flow to the condenser and affect the temperature distribution of the system at quasi-equilibrium. This modification is expected to reduce geysering and improve two-phase flow stability.

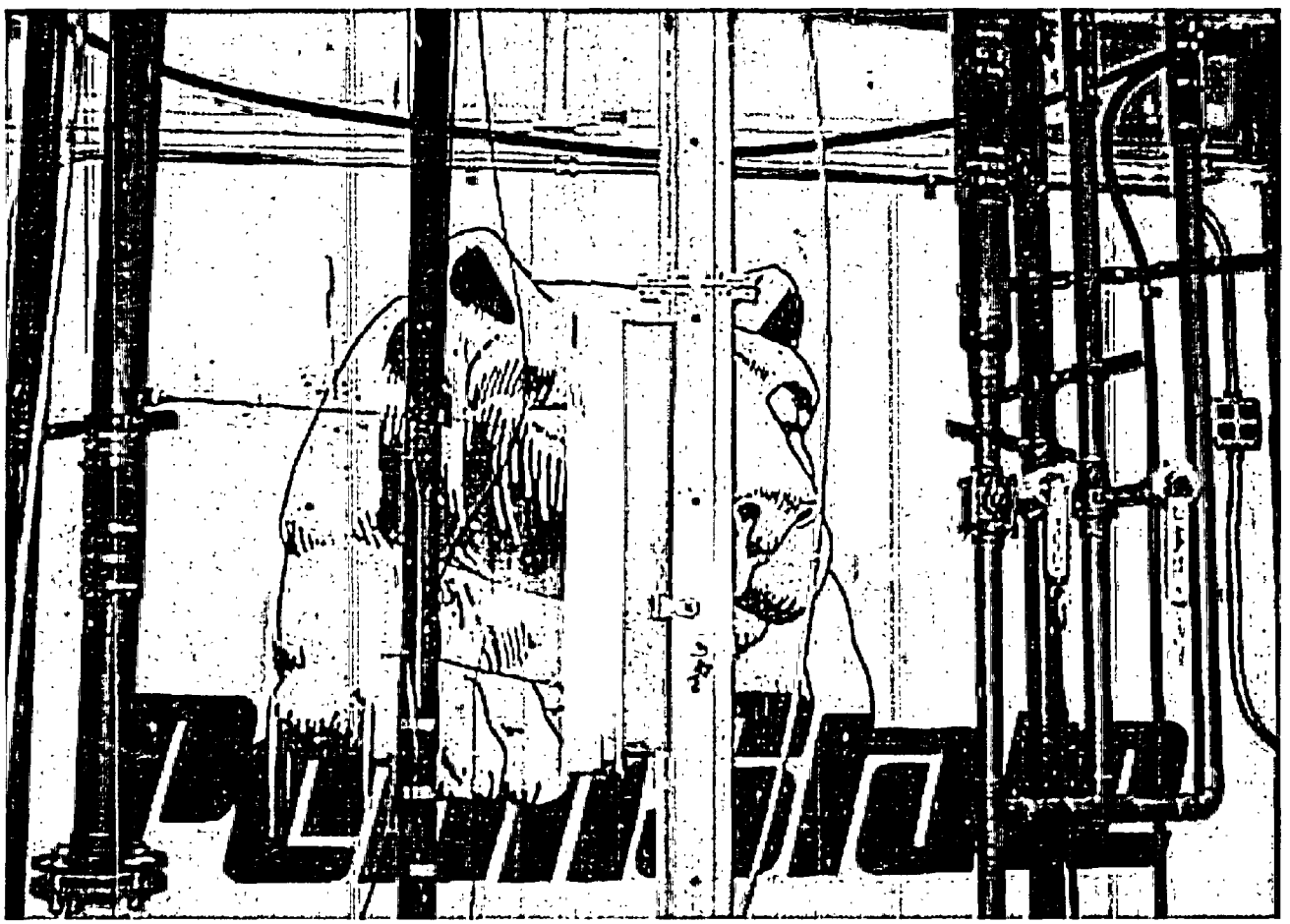


Figure 4. Modified downcomer section: This design eliminates flow reversal to the steam separator and/or main condenser.

One other modification involved the flow control: Flow rate is related to the temperature distribution along the loop and the temperature gradient between the hot and cold legs. There was no direct control over the flow, but through the condenser flow rate, which had a minuscule effect. With the addition of a flow control valve (Figure 5), one can restrict the maximum flow rate through the core and reduce the number of geysering cycles in the unstable two-phase flow regime. The electric motor actuated valve is equipped with a bypass line to guarantee a minimal flow rate in the case of a valve failure.

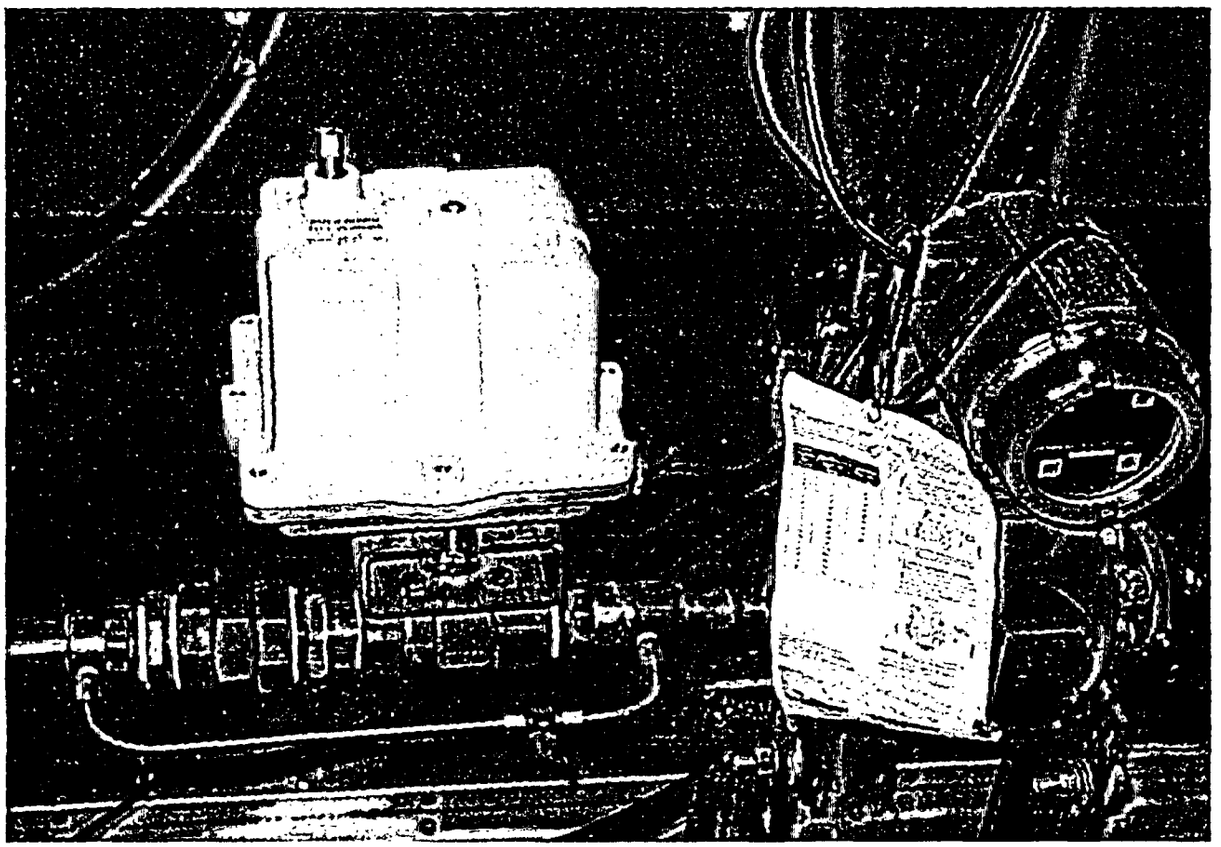


Figure 5. Electric motor actuated valve and bypass valve.

INSTRUMENTATION

The state of the loop is observed through a number of instrumentation:

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

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

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

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

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

A computer reads the measurements and displays them through an interface application designed in LabVIEW (Figure 6). This application also interfaces to the control the power signal for SCR's, which in turn controls the electricity input to the rod bundle.

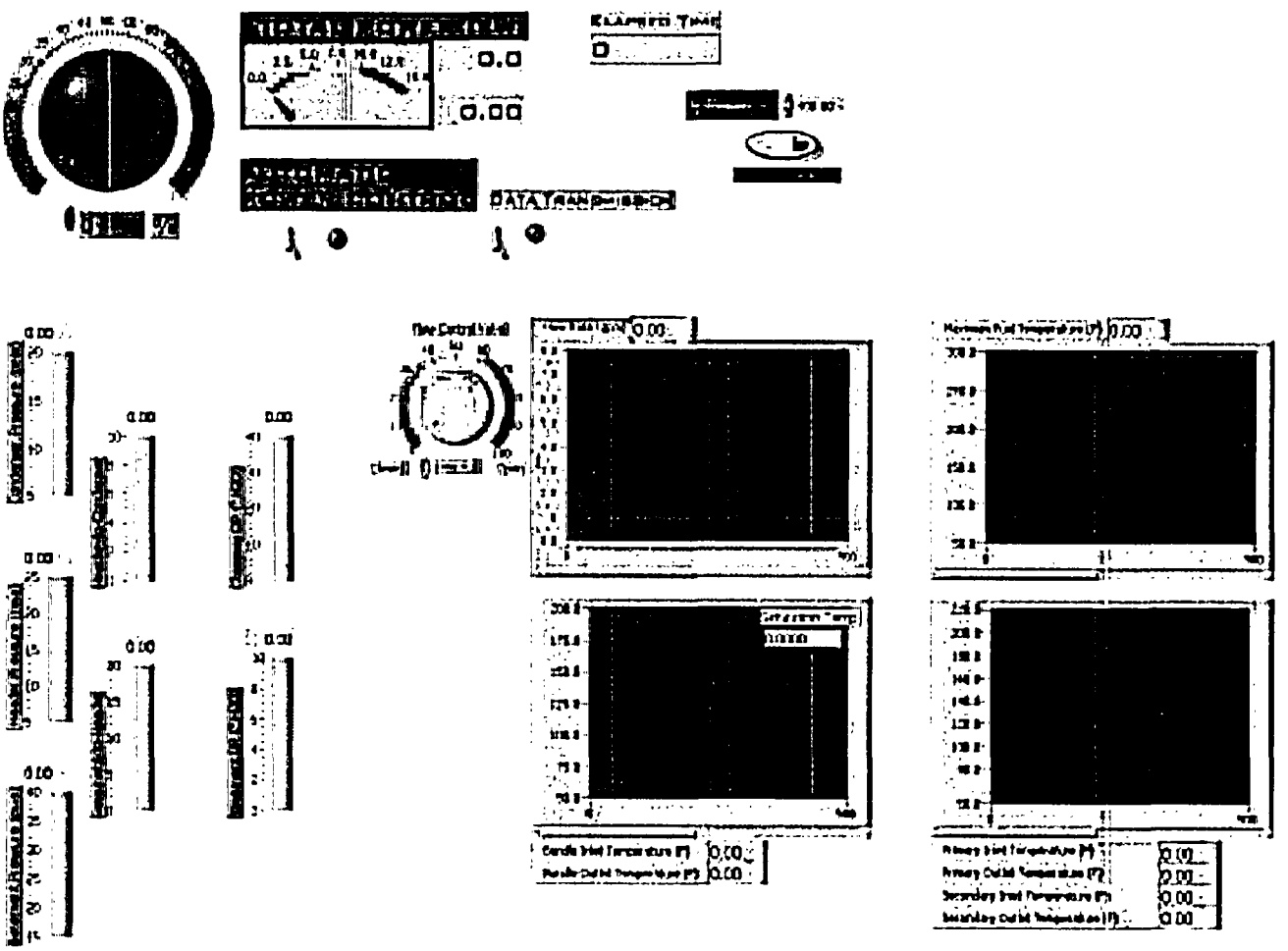


Figure 6 – Screenshot from the LabVIEW main control interface.

TYPES OF EXPERIMENTS

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

Single-Phase Natural Circulation Experiments

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

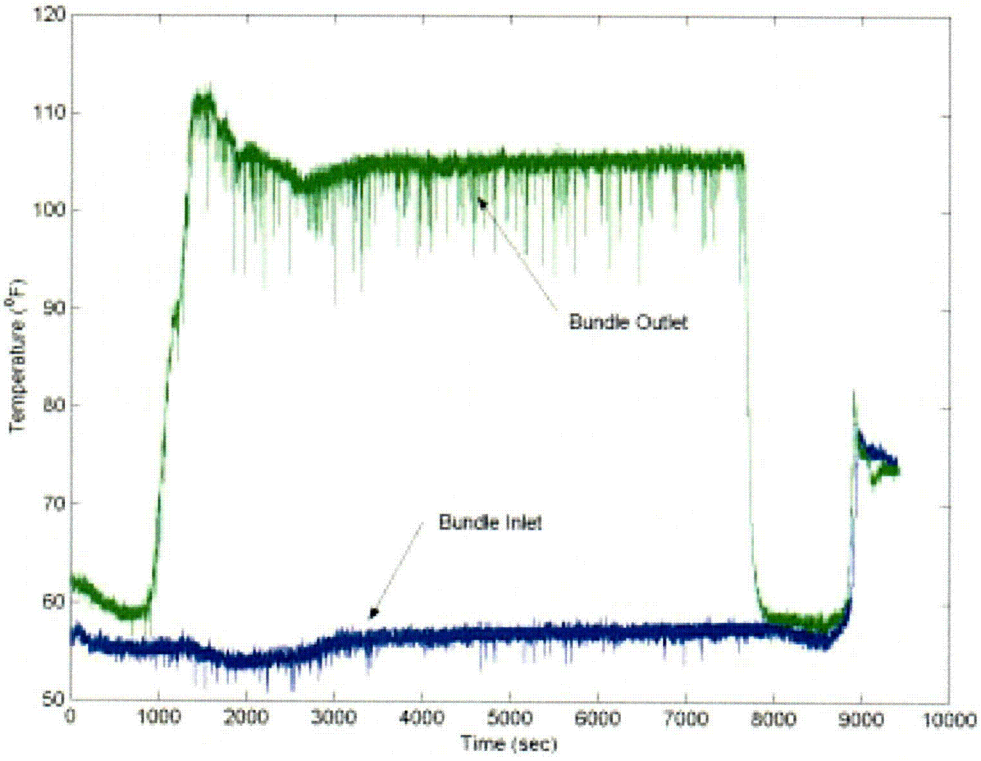


Figure 7 – ***History of the core mean temperatures during a single-phase flow.***

Figure 7 and Figure 8 show the fluid temperature behavior during the single phase natural circulation experiment along the core and in the main condenser. The flow becomes established as the temperature difference develops between the hot and the cold legs, as can be seen in Figure 9. The coolant channel axial temperature distribution is shown in Figure 10 for this experiment.

C02

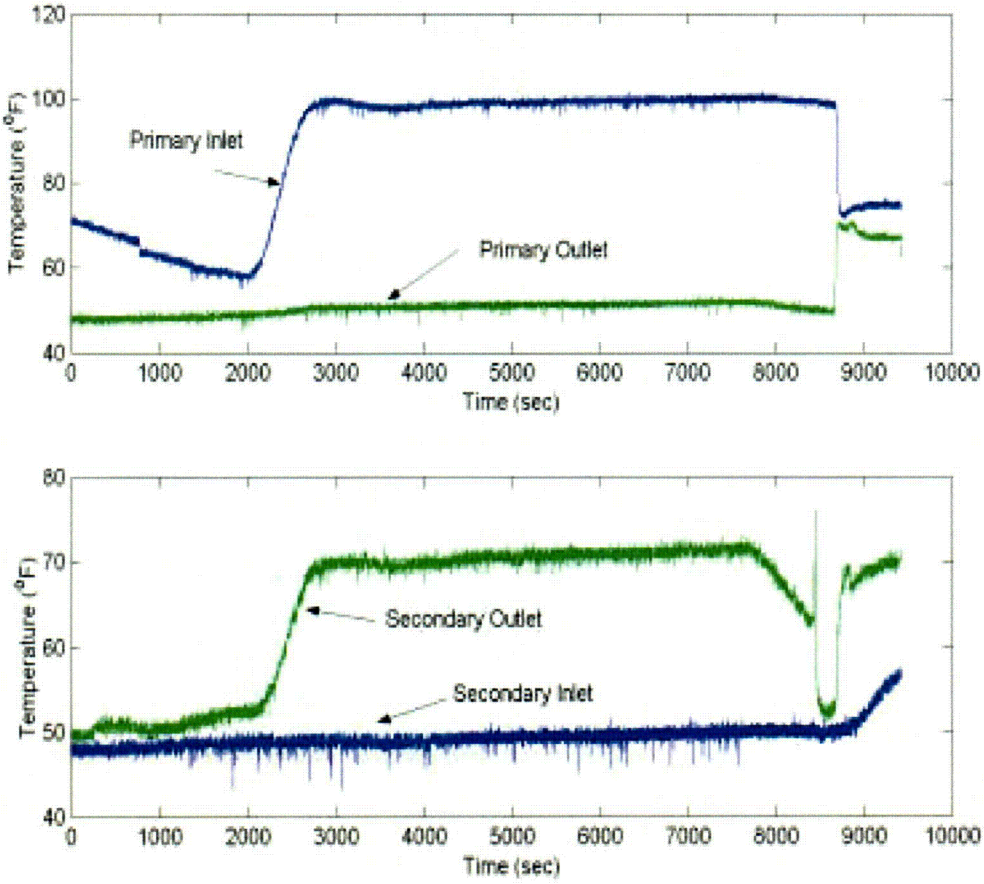


Figure 8 – ***Temperature history in the main condenser.***

C03

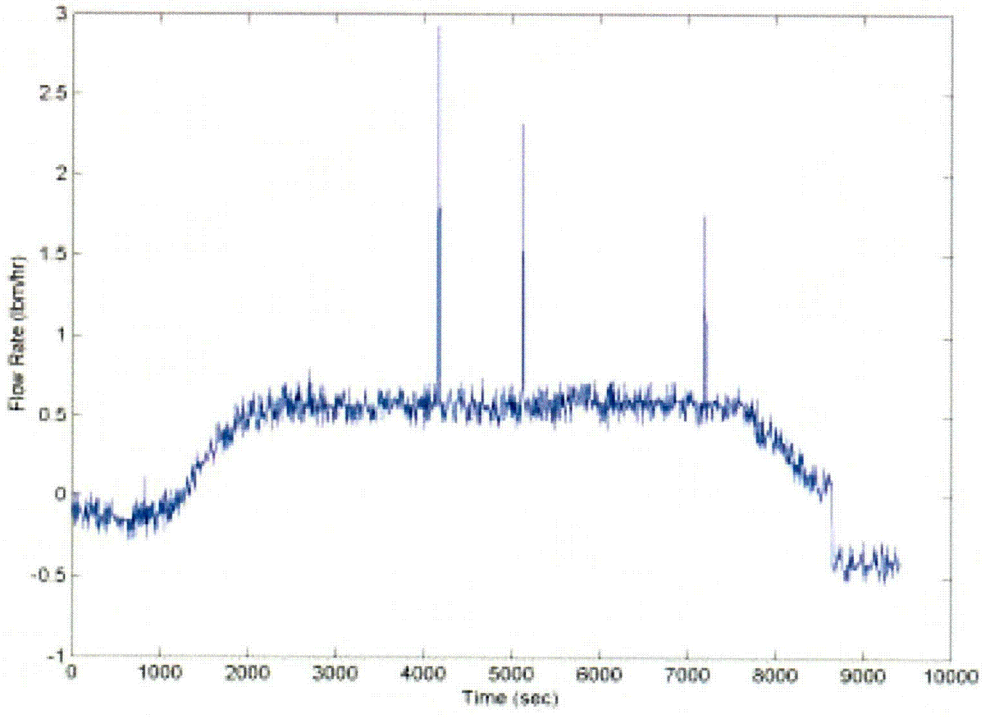


Figure 9 – ***Single-phase natural circulation flow rate.***

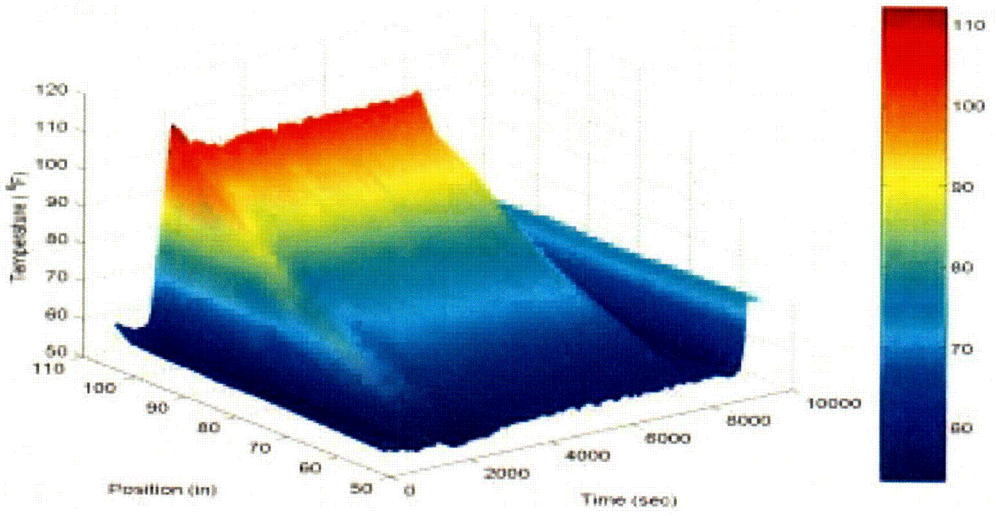


Figure 10 – ***3-D profile along the core of the fluid temperature for this particular experiment.***

C04

Two-Phase Natural Circulation Experiments

Two-phase natural circulation experiments have also been performed in the facility and are very useful for the students to observe the boiling process and flow regime behavior along the vertical channel, which contains the rod bundle. Subcooled nucleate boiling can be observed, with very small bubbles being formed at the heater rod surfaces. As the coolant is heated to saturation, bulk boiling occurs and several different flow regimes such as bubbly, slug, and churn-turbulent flow can be observed.

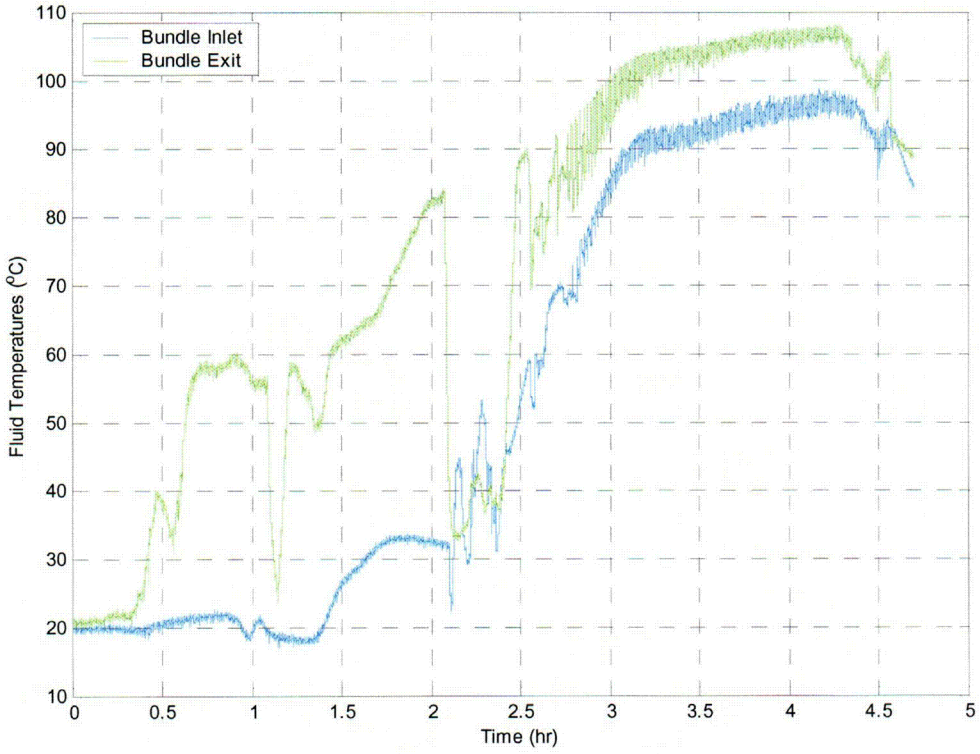


Figure 11 – ***Core fluid temperature history.***

The two-phase natural circulation experiments are initiated as a single-phase natural circulation test to heat the fluid to the saturation temperature. Once the fluid approaches saturation temperature, the facility is partially drained, which reduces the system pressure. As a result of the reduced system pressure, the remaining water in the facility starts to boil with lower heat input. Figure 11 shows the temperature of the bundle inlet and exit as the facility transitions into a two-phase mode after approximately three hours.

C05

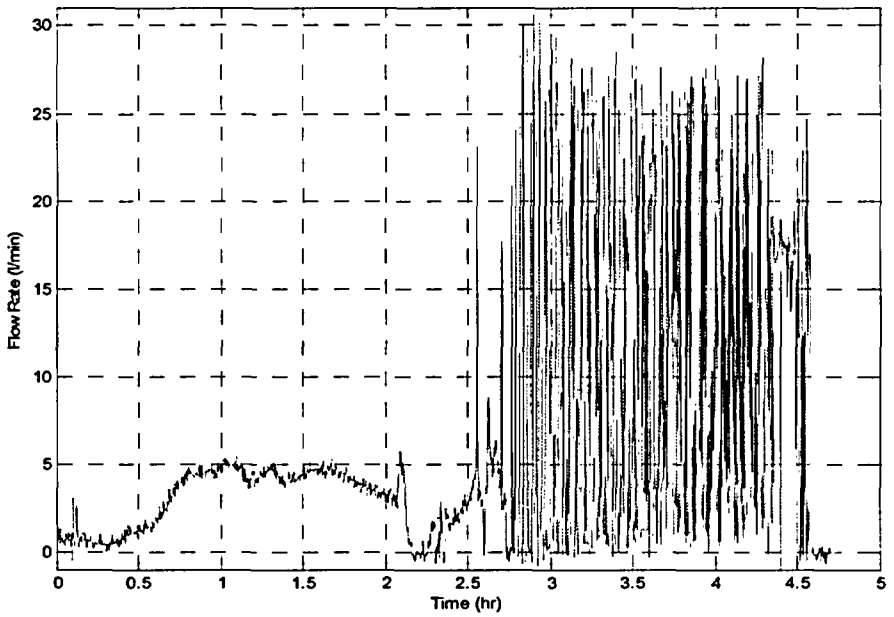


Figure 12 – Flow rate during the two-phase natural circulation experiment.

Figure 12 shows the stable single-phase natural circulation flow, which then transitions to a very oscillatory flow once the system is in two-phase natural circulation. The two-phase flow oscillation experiments are part of a Department of Energy NEER program, which studies BWR flow/power stability.

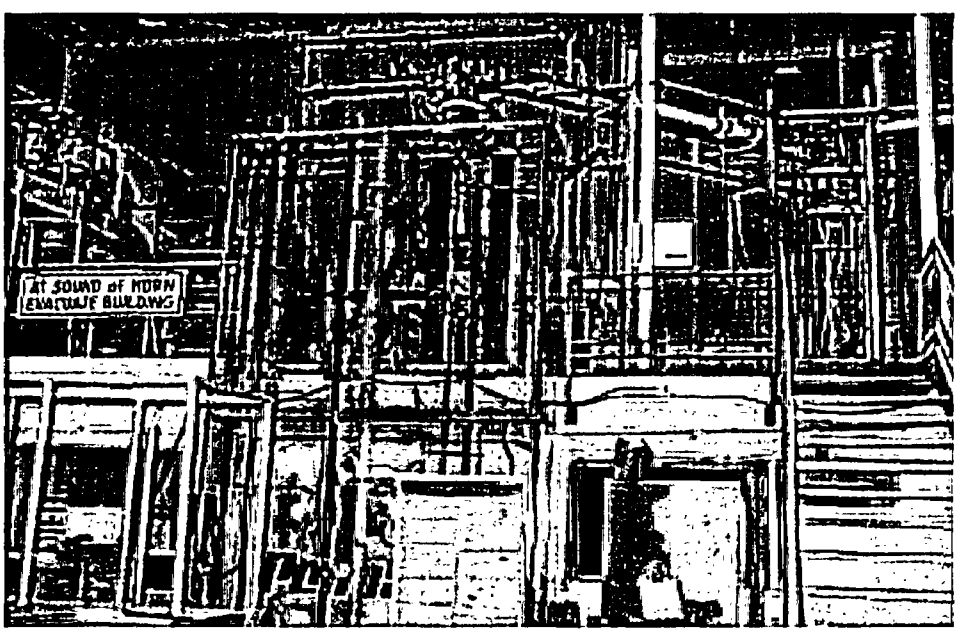


Figure 13 – The riser, chimney sections of the core; crossover leg, and steam separator.

CONCLUSIONS

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

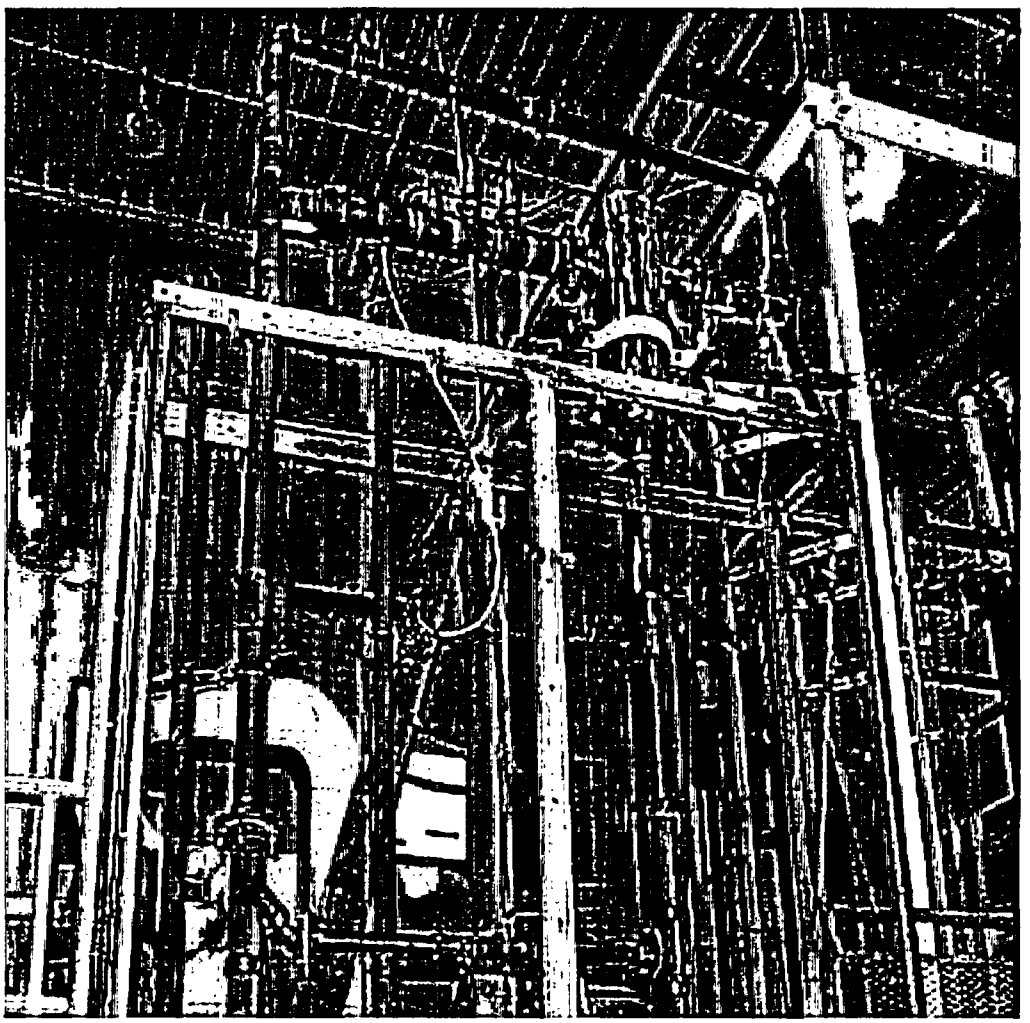


Figure 14 – A closer look to the crossover leg and the steam separator.

ANGULAR CORRELATIONS LABORATORY

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 16 years, measures four coincidences concurrently using cesium fluoride detectors. A second spectrometer was acquired 12 years ago, and it measures four coincidences concurrently using barium fluoride detectors. A third spectrometer was set up eight 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.

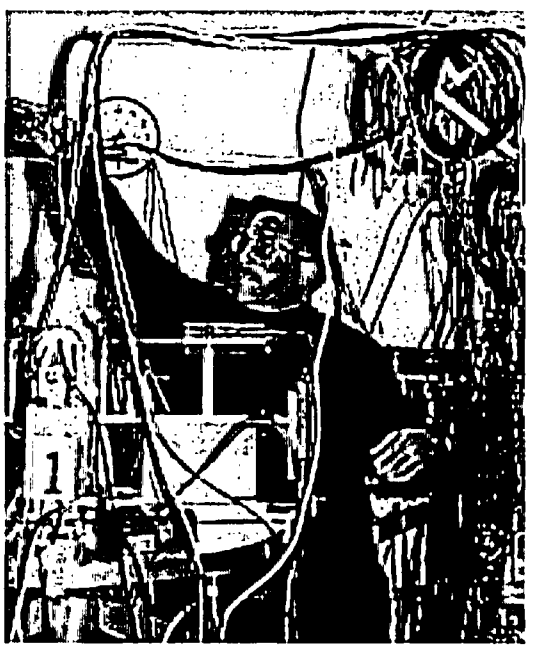


Figure 1. Prof. Catchen inserts a sample into a high-temperature sample furnace, which is mounted in the center of the four-detector array of the perturbed-angular-correlation spectrometer.

Currently Professor Catchen is executing a research program funded by the Petroleum Research Fund of the American Chemical Society. It is titled: "Drag Reduction in Turbulent Flows: Direct Observation of Very Rapid Fluctuations in Polymer-Solvent Interactions." Low concentrations of linear polymers can greatly reduce drag in various types of fluid transport. Although scientists have identified many drag-reducing polymers, investigators have not been able to observe directly the polymer-solvent interactions causing drag reduction. For this purpose, Professor Catchen is using PAC spectroscopy.

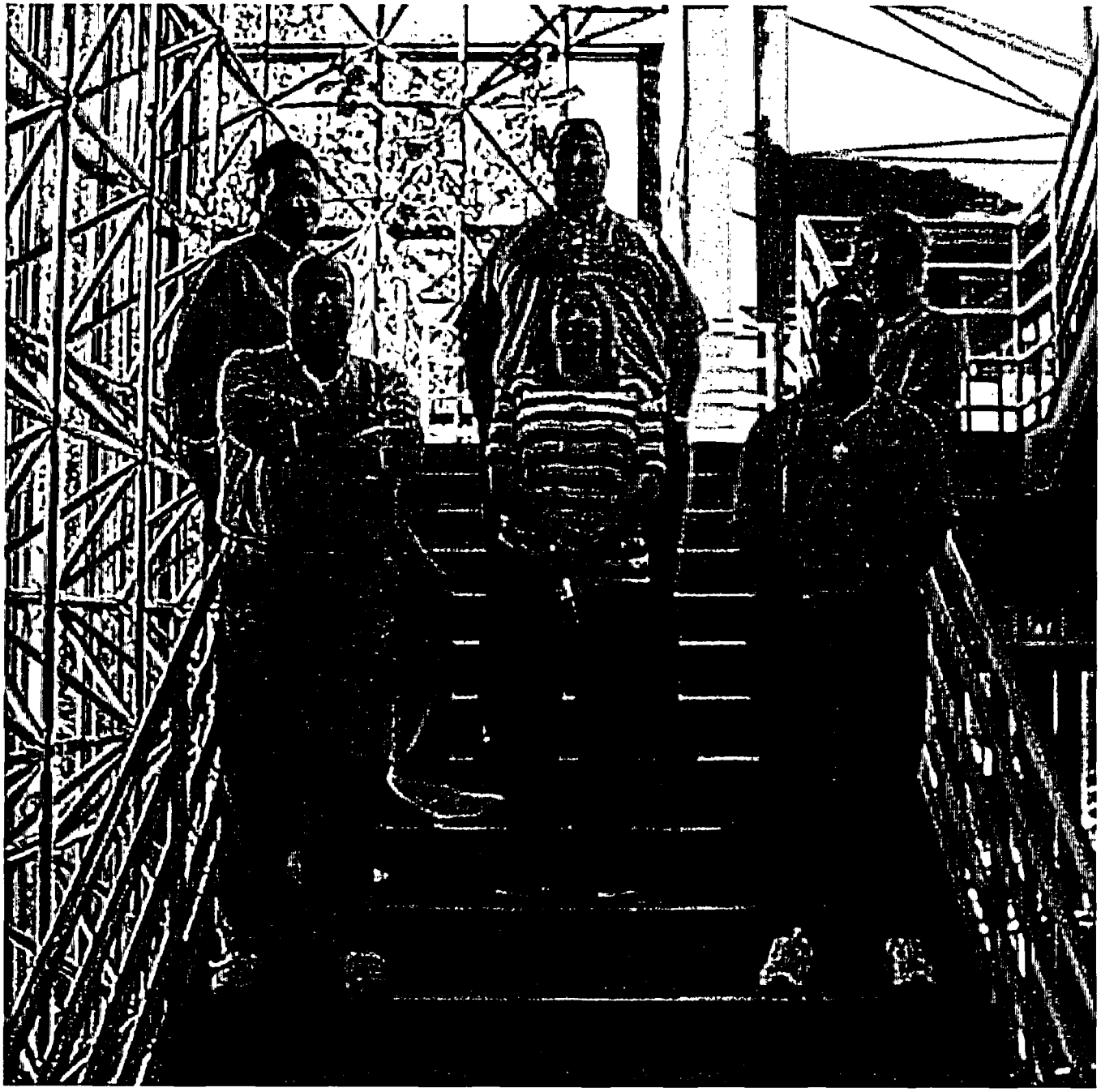
The PAC technique is based on substituting a radioactive probe atom such as ^{111}In or ^{181}Hf into a specific site in a chemical system. Because these atoms have special nuclear properties, the nuclear (electric-quadropole and magnetic-dipole) moments of these atoms can interact with the electric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

Static nuclear electric-quadropole 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 isvery 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 XII of this report.

ENVIRONMENTAL HEALTH & SAFETY



ENVIRONMENTAL HEALTH & SAFETY

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

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

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

ALARA PROGRAMS

Figure 1. Mark Linsley of radiation protection surveys samples in a laboratory.

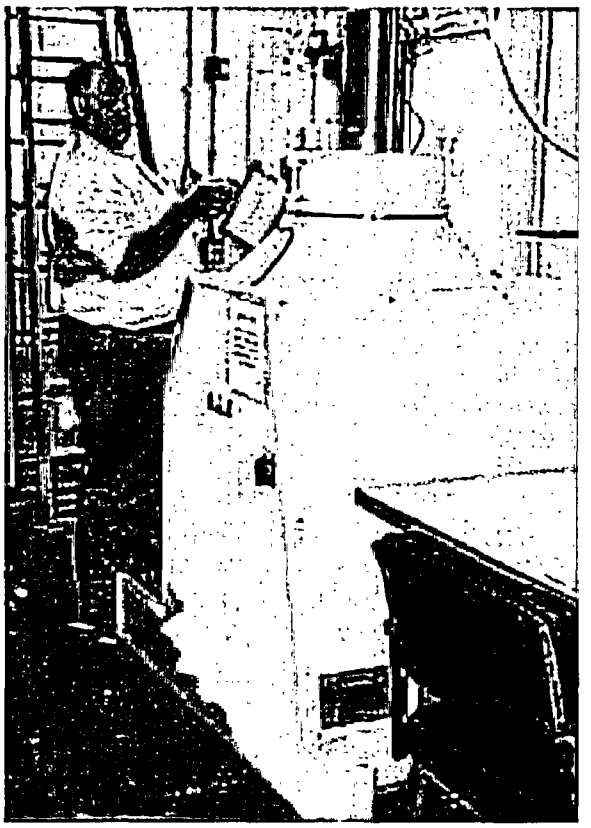


Figure 2. Greg Herman of radiation protection surveys around the GammaCell 220 Excel Irradiator.

This year EHS performed over 134 radiation surveys at the RSEC. Survey results showed that there were no radioactive contamination surveys or radiation surveys above established limits and radioactive material was being handled in a safe and controlled manner. The surveys were conducted to detect possible transferable contamination from radioactive materials work or to survey radiation sources such as activation products, sealed sources, equipment, and reactor operations. The radioactive contamination surveys are performed in laboratories where radioactive materials are used and in the balance of the RSEC's public areas to ensure that no radioactive material has been transferred to these areas. Both the contamination surveys and the radiation surveys are redundant to the surveys performed routinely by the RSEC staff. The redundancy of the contamination and radiation surveys is fundamental to the University's ALARA program.

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

SERVICE

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

From September to November, EHS personnel provided support for ten shipments of Pathfinder fuel off campus. In July RSEC received a new Co-60 irradiator. EHS personnel were present to perform the necessary incoming and setup surveys.

Figure 3. Dave Bertocchi of radiation protection and Thierry Daubenspeck, senior reactor operator, load a shipment of RAM.

LICENSING AND REGULATORY REQUIREMENTS

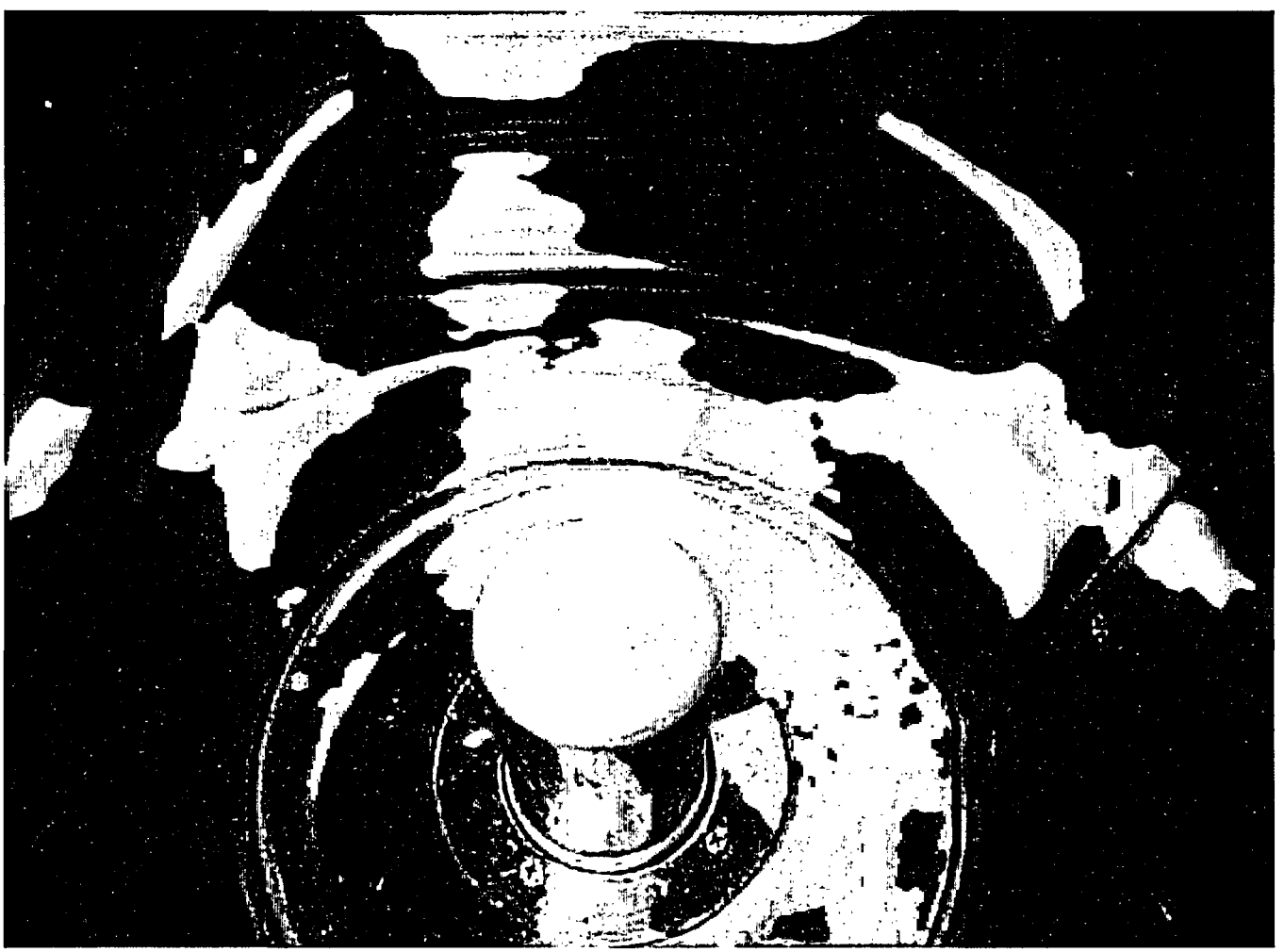
During the past year Eric Boeldt, Penn State's radiation safety officer (RSO), and Candace Davison (RSEC) renewed the NRC license for the Co-60 pool. Final approval was received in January of this year; the license is now valid until 2014.

Dosimetry requirements are administered by EHS and dosimetry is issued to RSEC personnel to measure staff, student, and worker radiation exposures. This year EHS issued a total of 564 dosimeters to RSEC personnel, there were no exposures above unsafe levels. Administration of the dosimeter program includes issuing dosimeters, processing dosimeters and maintaining all dosimetery records. EHS has administered a thermal neutron dosimeter program to check exposures more accurately for those working around the neutron radiography laboratory. One neutron dosimeter is a permanent fixture in the laboratory, and individuals wear the others as they work in the lab. A total of 68 thermal neutron dosimeters were monitored with no indication of any measurable thermal neutron exposures to personnel. Self-reading dosimeters are issued to transient persons and visitors to the RSEC. The information for the temporary dosimetry is documented in logbooks maintained by the administrative staff at the facility. The RSO is an active member of the Reactor Safeguards Committee.

Training

Training programs provided by EHS to the RSEC are license and regulatory driven. Training covering the requirement of shipping limited quantities of radioactive material was given to three reactor personnel this year. Also, approximately 43 new reactor personnel and students attended the radiation safety orientation. Required retraining for all radiation workers was provided to the RSEC by means of a newsletter distributed to all laboratory supervisors. All RSEC personnel also completed the annual Chemical & Chemical Waste Refresher Training. Three new employees and students attended the initial Chemical & Chemical Waste Training program. The RSEC has a history of being in compliance with Penn State's Chemical & Chemical Waste Handling programs.

RADIATION SCIENCE & ENGINEERING CENTER RESEARCH AND SERVICE UTILIZATION



RSEC RESEARCH & SERVICE UTILIZATION

Research and service continues to be the major focus of the RSEC. A 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 involve five technical reports, presentations or papers, 36 publications, six master's theses, and two doctoral theses. The examples cited are not to be construed as publications or announcements of research. The publication of research utilizing the RSEC is the prerogative of the researcher.

Appendix A lists all university, industrial, and other user 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 of other affiliation. During the past year, 47 students and staff members, 37 graduate students, and 24 undergraduate students have used the facility for research. This represents a usage by 13 departments or sections in five colleges and one research unit of the University. In addition, 53 individuals from 28 industries, research organizations, or other universities used the RSEC facilities.

SECTION A. PENN STATE RESEARCH UTILIZING THE FACILITIES OF THE RSEC

Mechanical and Nuclear Engineering Department

NE 444, REACTOR OPERATIONS LABORATORY

Participants: C.F. Sears, Professor and Director, RSEC

NE 444 is a one credit laboratory course which provides students the opportunity to individually operate the Penn State TRIGA Reactor and perform selected reactor experiments including checkout, approach to critical, numerous startups, power operations in manual and automatic control, power coefficient measurements, rod worth measurements both manually and with a reactor computer, square wave operations and pulse operations. This brings a hands on application to their analytical and theoretical class work.

NE 450, UNDERGRADUATE LABORATORY–RADIATION DETECTION AND MEASUREMENT

Participants:
R.M. Edwards, Professor
J.S. Brenizer, Professor
C.F. Sears, Director, RSEC
T.L. Flinchbaugh, Associate Director for Operations
M.E. Bryan, Research Engineer
B.J. Heidrich, Research Assistant

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

The Nuclear Engineering 450 course is the first of two 3-credit laboratory courses required of all Penn State nuclear engineering undergraduates and is typically taken during the Spring of the junior year. Each weekly laboratory exercise consists of two lectures and one laboratory session. 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.

The wide range GM detector and BF3 detector are studied in the Cobalt Irradiation Facility. Ion chambers are studied with the reactor.

NE 451, UNDERGRADUATE LABORATORY OF REACTOR EXPERIMENTS

Participants:
R.M. Edwards, Professor
C.F. Sears, Director, RSEC
T.L. Flinchbaugh, Associate Director for Operations
M.E. Bryan, Research Engineer
B.J. Heidrich, Research Assistant

Services Provided: Laboratory Space, Machine Shop, Electronics Shop, Neutron Irradiation Using Subcritical Pile, Reactor Instrumentation and Support Staff

The Nuclear Engineering 451 course is the second of two 3-credit laboratory courses required of all Penn State nuclear engineering undergraduates and is typically taken during the Fall of the senior year. Each weekly laboratory exercise consists of two lectures and one laboratory session. By the beginning of the senior year, the students have already covered the LaMarsh Introduction to Nuclear Engineering text including reactor point kinetics. The 451 course emphasizes experiments using the instrumentation that was covered in NucE 450 and is divided into two "tracks". These tracks can be coarsely described as TRIGA and non-TRIGA experiments. The non-TRIGA track includes three graphite pile experiments.

In 2003, 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
7. Source Affects and Feedback

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 our undergraduates do not receive a complete introduction to feedback control. The reactor control experiment interfaces a general purpose PC computer to an Experimental Changeable Reactivity Device (ECRD). Control experiments make use of one of two ERCD's implemented as a moveable experiment where an aluminum tube containing an absorber material is positioned within the central thimble of the reactor. The first ERCD with a worth of approximately $0.35 has a maximum insertion rate of about $0.12/s while the second with a worth of about $0.94 may be inserted up to $0.35/s. ERCD #1 is used for experiments of up to 65 percent where temperature changes produce significant reactivity changes. ERCD #2, added in 2000, is for use at low power (less than 0.1 percent) where temperature change and its reactivity effect are negligible. The SIMULINK Real Time Workshop is used to implement an experimental control algorithm. The SIMULINK 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.

NEUTRON IRRADIATED SILICONE CARBIDE STUDIED USING POSITRON ANNIHILATION LIFETIME SPECTROSCOPY

Participants: G. Catchen, Professor
A. Motta, Professor

C. Tyree, Graduate Student
C. Trivelpiece, Undergraduate Student
A. Dulloo, Westinghouse Electric Corporation
F. Ruddy, Westinghouse Electric Corporation

Services Provided: Neutron Irradiation, Gamma Irradiation Monitoring, Machine Shop, and Laboratory Space

Sponsor: FERMI Group in conjunction with Westinghouse Electric Corporation

Chris Tyree (MS student) and Cory Trivelpiece (undergraduate) are conducting research on silicone carbide wafers that are being considered for radiation detection equipment, under the supervision of G. Catchen and A. Motta. The semiconductor material is very resilient at high temperatures and could be used inside the pressure vessel of commercial reactors, but its performance degrades over time under neutron flux. The research project's main focus is on what kinds of defects are caused by neutron irradiation and at what temperature will the sample anneal and return to a defect-free state. Operation at this temperature would mean self-anneal of the devices and no degradation. Irradiation of the samples is conducted at the Breazeale nuclear reactor facility along with the analysis and annealing of the samples. Analysis of the defects present in the samples after post-irradiation annealing is performed using Positron Annihilation Lifetime Spectroscopy. The research is funded by the FERMI group and is done in conjunction with Westinghouse Electric Corporation.

Masters Thesis:

Tyree, Chris, "*Neutron Irradiated Silicon Carbide Studied Using Positron Annihilation Lifetime Spectroscopy.*" Advisors: G. Catchen, A. Motta

STUDY OF WATER DISTRIBUTION AND TRANSPORT IN A POLYMER ELECTROLYTE FUEL CELL USING NEUTRON IMAGING

Participants: M. Mench, Assistant Professor
J. Brenizer, Nuclear Engineering Program Chair and Professor
K. Ünlü, Professor

P.A. Chuang, Post Doctoral.
N. Pekula, Graduate Student
A. Turhan, Graduate Student
K. Heller, Graduate Student

Services Provided: Neutron Beam Laboratory

Sponsor: General Motors Corporation, RSEC

INTRODUCTION

Due to its high efficiency, low operating temperature (~30-80°C), and rapid evolution since over the past decade, the polymer electrolyte fuel cell (PEFC) is currently under intense research and development. Compared to present power systems, such as the internal-combustion engine, fuel cells are advantageous for several reasons and present a promising future. The operating efficiencies can reach as high as 50-90% for units and also pollutants such as nitrous oxides and particulate matter are eliminated, while carbon dioxide and carbon monoxide are reduced to near zero.

Figure 1 shows the basic operation of a hydrogen PEFC. Hydrogen is supplied to the anode of the fuel cell while oxygen, usually taken from the air, is supplied to the cathode. The electrochemical oxidation reaction at the anode produces hydrogen ions and electrons.

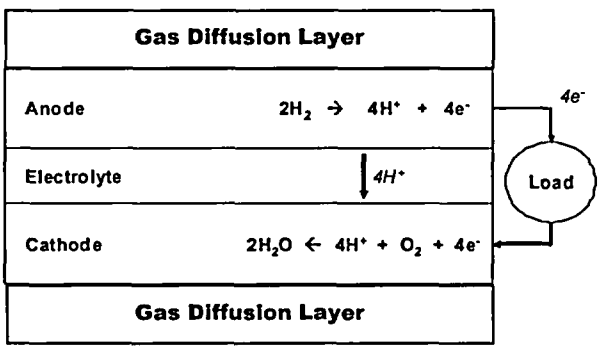


Figure 1: Simplified Schematic of PEFC

The flow of the electrons through an external circuit powers a load. The ions produced at the anode are transported through an ionically conductive polymer electrolyte to the cathode, where water is produced. A ~10-20 μm platinum catalyst layer is typically employed at both electrodes to reduce the activation energy for the electrochemical reactions. Covering each electrode is a 200-400 μm porous carbon fiber gas diffusion layer (GDL). The GDL functions to enable reactant transport to, and product from the catalyst layer, while providing conductivity for electron transport.

In a PEFC, the level of water must be precisely balanced. Adequate water vapor must be available to maintain high electrolyte ionic conductivity and ensure suitable performance. However, if excessive water is present in the liquid phase, it can block pores in the catalyst and GDLs, hindering the transport of reactants to the catalyst. This phenomenon is known as "flooding", and greatly diminishes cell performance. Due to the delicate balance between the benefit of saturated flow and the deleterious effects of flooding concomitant with liquid water accumulation, there is extensive ongoing research to more fundamentally understand two-phase water transport in PEFCs, to enable performance and design optimization.

Although there have been numerous models presented in literature that predict the water production and transport phenomenon in fuel cells, there has been little research in experimental visualization and quantification of the liquid water distribution and transport. Neutron radiography and radioscopy are excellent non-intrusive techniques for visualization and quantification of the two-phase flow within the fuel cell in real time or steady-state.

EXPERIMENTAL SETUP

The neutron radioscopy system and thermal neutron beam from the Breazeale Nuclear Reactor at the Penn State Radiation Science and Engineering Center was utilized in this study. Specialized image processing hardware was developed for the analysis, storage and presentation of the collected images.

An integrated test station at the Neutron Beam Lab (NBL) was built to control and monitor the fuel cell operating parameters. The NBL Test Station (NBLTS) is isolated from the neutron beam source, as illustrated in Figure 2. The station can accommodate various sized fuel cells (up to 22.8 cm diameter in a single frame) for neutron imaging processes while the following conditions are controlled by the operator on the station's control panel:

- Gas flow rates
- Inlet gas temperature and humidity
- Cell temperature
- Current/Voltage draw
- Operating pressure
- Nitrogen purge

The visualization and quantification of the water distribution in the fuel cell is performed by neutron radioscopy and radiography techniques. Data acquisition and data presentation details for these techniques are described in the next section of this report.

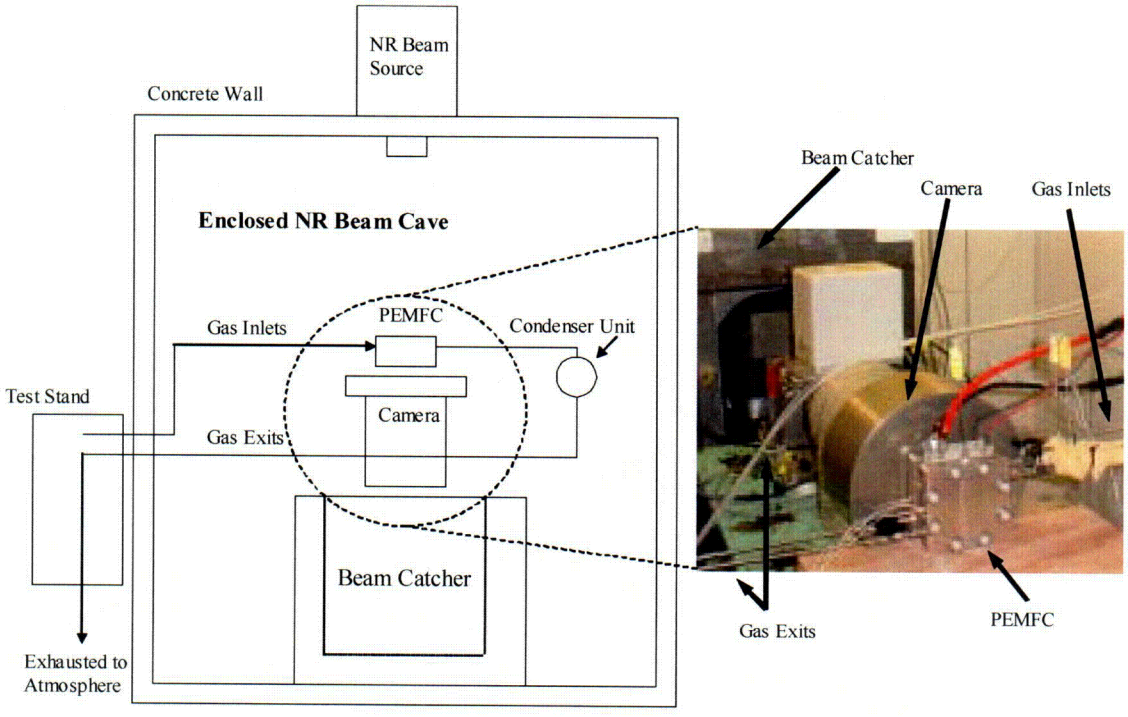


Figure 2: Test station for fuel cell imaging at the NBL

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NEUTRON RADIOGRAPHY RESULTS [11]

A series of neutron radiographs were collected using the fuel cell and imaging setup. The cell temperature (80°C) and gas flow back pressure (0.274 MPa) were maintained constant throughout the experiments whereas the relative humidity of the anode and cathode were maintained at 100 percent at 80°C for all tests. Figure 3 shows substantial water accumulation near the fuel cell exit (lower left corner) for radiographs taken at the low current density condition, i.e. 0.05 A/cm^2. The images show liquid water occupying a large portion of the gas flow channels causing channel flooding inside the fuel cell. From the flow channel geometry (2-channel pass design on anode and 3-channel design on the cathode) it can be concluded that the liquid water is on the anode side of the cell.

Figure 4 shows three separate radiographs taken at the high current density condition, i.e. 1.0 A/cm^2. The images show that highly dispersed liquid droplets are present in the lower half of the fuel cell, and that the flow channels near the cell inlet (upper third) contain almost no liquid water at all. This is most likely due to the water vapor being continually added to the gas flow stream along the flow channel path via generation until saturation. Through the cell exit, water accumulation is observed due to liquid saturation of the gas flow.

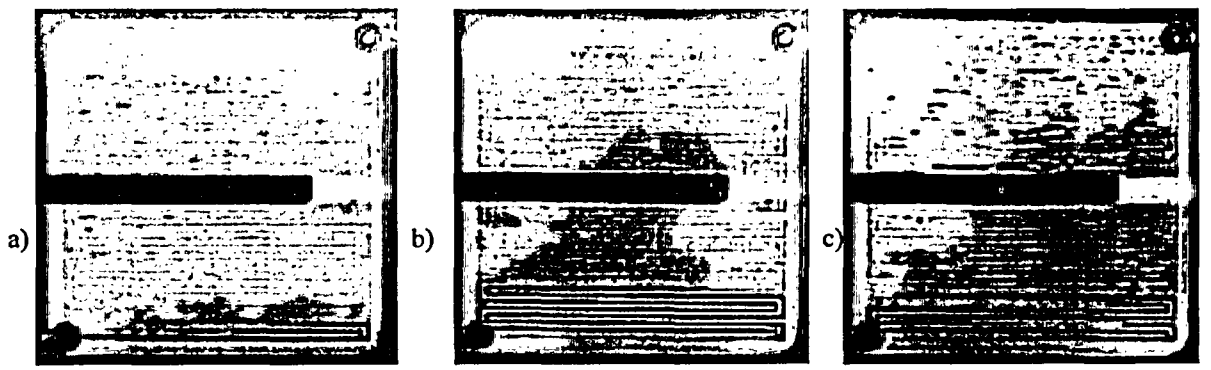


Figure 3: Neutron radiographs a) ξ_c =10.0; 2.5 A; 0.843 V, b)=6.5; 50 A; 0.857 V, c)=6.0; 2.5 A; 0.868 V

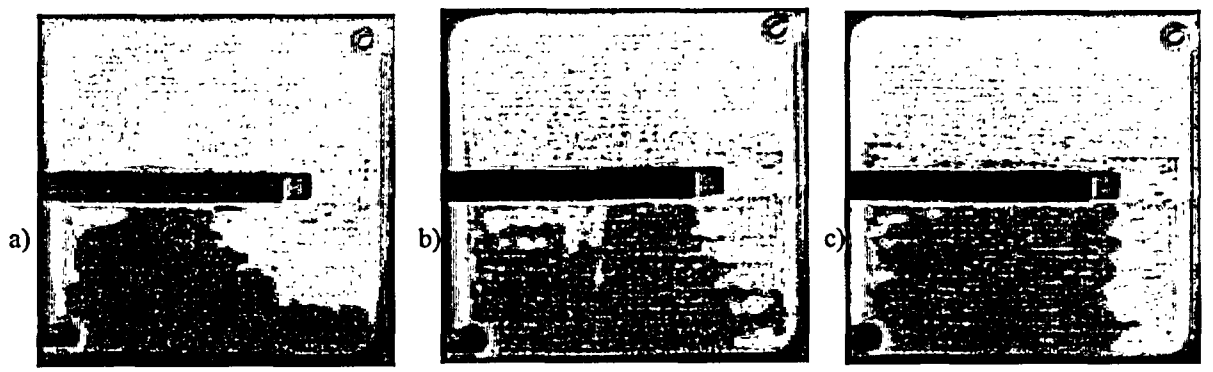


Figure 4. Neutron radiographs a)=2.0; 50 A; 0.725 V, b)=1.4; 50 A; 0.625 V, c)=1.3; 50 A; 0.600 V

REAL-TIME NEUTRON RADIOSCOPY RESULTS

Real-time (30 fps) neutron radioscopy video of the operating fuel cell was recorded for a wide variety of test conditions. Video was recorded for approximately 20 minutes for each experiment. The high temporal resolution of the radioscopy procedure allowed for the liquid water accumulation and transport in the cell to be directly observed. Further image analysis gave insight into the characteristics of the liquid water droplet behavior and flow velocities.

The results of velocity measurements indicate that the droplet velocity cannot be assumed to be on the same order of magnitude as the gas flow velocity for the fuel cell configuration and conditions tested, and a homogeneous, no-slip model of the two-phase channel flow is inappropriate for channel level two-phase modeling.

CONCLUSIONS

Neutron radiography and radioscopy yield excellent spatial and temporal resolution for the investigation of water transport phenomenon and the measurement of liquid water inside an operating polymer electrolyte fuel cell. The results showed that the amount of water accumulation in the flow channels highly depends on current density. It was also shown that channel-level liquid droplet velocity is not constant, and changes substantially due to interactions with the flow channel walls and other droplets. The maximum velocity of the droplets are an order of magnitude less than the reactant gas flow.

REFERENCES

1. N. Pekula , K. Heller, P. A. Chuang, A. Turhan, M.M. Mench, J. S. Brenizer, K. Ünlü, " Study of Water Distribution and Transport in a Polymer Electrolyte Fuel Cell Using Neutron Imaging," Nuclear Instrumentation Methods, Section A. (Accepted for publication)

NEUTRON RADIOGRAPHY MEASUREMENTS OF WATER TRANSPORT IN AN OPERATING PEM FUEL CELL

Participants: M. Mench, Assistant Professor
J. Brenizer, Nuclear Engineering Department Chair and Professor
K. Ünlü, Professor

P. A. Chuang, Post Doctoral
N. Pekula, Graduate Student
K. Heller, Graduate Student
A. Turhan, Graduate Student
S. Soung, Schreyers Honor Undergraduate Student

Services Provided: Neutron Radiography, Laboratory Space, Machine Shop

Sponsor: Auto Manufacturer, $150,000

Many automotive companies are developing fuel cell systems as a high efficiency, low emissions technology for automobile propulsion. Proton exchange membrane (PEM) fuel cells combine hydrogen and oxygen to produce electrical current and only water and heat as by-products. The proper management of the water produced in the cathodic oxygen reduction reaction is essential to efficient fuel cell operation. The polymer membrane in the fuel cell must be well hydrated to facilitate proton transfer, but if too much water is present, flooding will occur which restricts reactant oxygen from reaching catalytic sites at the membrane surface. Also, because flooding affects the temperature gradients in the plane of the proton-conducting membrane, it is suspected that the phenomenon can impact the long-term durability of the fuel cell.

The sponsor is actively developing measurement methods that will aid in assessing all aspects of fuel cell operation for automotive applications. However, ascertaining where liquid water is generated within the fuel cell, and how it is transported on both the anode and cathode sides, remains a difficult experimental problem. Perhaps the only method available for measuring full-area water distribution in an operating fuel cell is the neutron imaging technique. Penn State University (PSU) has developed a high level of expertise in this field, and has reported previous experimental work on the application of neutron imaging to measure liquid water distributions in metallic enclosures. This project will examine water distribution in operating PEFCs.

Masters Thesis:

N. Pekula, "Visualization and Measurement of Water Accumulation and Transport in an Operating PEFC Using Neutron Imaging", M. S. Thesis, Spring 2004.

Reports to Sponsor:

Pekula, N., Ünlü, K., Brenizer, J., and Mench, M. M. 2003. Neutron Radiography Measurements of Water Transport in an Operating PEM Fuel Cell. *Final 2003 Report to General Motors*

Invited Talks:

N. Pekula, M. M. Mench, K. Heller, K. Ünlü, and J. Brenizer "Neutron Imaging of Two-phase Transport in a Polymer Electrolyte Fuel Cell," American Nuclear Society Spring Meeting, 2004.

M. M. Mench, "Advanced Diagnostics for PEFCs," Gordon Research Conference on Fuel Cells, Bristol, Rhode Island. July 2004.

M. M. Mench, "Two-phase Flow Visualization in ***PEFCs***-using Neutron Radiography to visualize and quantify liquid water transport in the diffusion media and flow channels of a ***PEFC.***", 2004 International Conference on Fuel Cells, Taiwan, R.O.C., 2004.

M. M. Mench and N. Pekula, "Neutron Imaging of Fuel Cells," United Technologies Research Center, Connecticut. February 2004.

Other Technical Presentations:

Pekula, N., Heller, K. Cetiner, S. M. Brenizer, J. Mench, M. M. and Ünlü K. 2004. Neutron Imaging and Quantification of Water Distribution and Transport in a Polymer Electrolyte Fuel Cell. *International Topical Meeting on Neutron Radiography* ITMNR-5, Germany.

DISTRIBUTED DIAGNOSTICS AND VISUALIZATION OF POLYMER ELECTROLYTE FUEL CELL PERFORMANCE DURING FREEZE-THAW CYCLING

Participants:	M. Mench, Assistant Professor J. Brenizer, Nuclear Engineering Department Chair and Professor K. Ünlü, Professor S. Soung, Schreyers Honor Undergraduate Student
Services Provided:	Neutron Radiography, Laboratory Space, Machine Shop
Sponsor:	Automotive Manufacturer, $800,000 for 4 years

The vision of the newly started project is a comprehensive four-year characterization study of polymer electrolyte fuel cell phenomena during freeze-thaw cycling. This break- through study will be conducted using the advanced distributed diagnostic capabilities uniquely available at the Penn State Fuel Cell Dynamics and Diagnostics Lab (FCDDL). The project consists of the following major tasks, Task 2 is relevant to the radiation science and engineering center (RSEC):

Task 1. Highly detailed distributed performance measurement and analysis of freeze-thaw cycling including current, species, temperature, and high frequency resistance (HFR) data.

Task 2. Freeze-thaw frozen and liquid water visualization and mass distribution quantification and analysis with Neutron Imaging.

Task 3. In-plane and through-plane thermal transport characterization for thin-film PEFC materials using micro and/or nano-sized thermocouple sensor technology.

Task 4. Ph.D. study and training of auto company personnel at Penn State.

NEUTRON RADIOGRAPHY MEASUREMENTS OF WATER TRANSPORT IN PEFCs

Participants: M. Mench, Assistant Professor
J. Brenizer, Nuclear Engineering Department Chair and Professor
K. Ünlü, Professor

P. A. Chuang, Post Doctoral
K. Heller, Graduate Student
A. Turhan, Graduate Student

Services Provided: Neutron Radiography, Laboratory Space, Machine Shop

Sponsor: Auto Manufacturer, $75,000

This project is to develop measurement methods that will aid in assessing all aspects of fuel cell operation for automotive applications. We seek to elucidate liquid water transport phenomena in the diffusion media (DM) and flow channels of an operating polymer electrolyte fuel cell. However, ascertaining where liquid water is generated within the fuel cell, and how it is transported on both the anode and cathode sides, remains a difficult experimental problem. Perhaps the only method available for measuring full-area water distribution in an operating fuel cell is the neutron imaging technique. Penn State has developed a high level of expertise in this field, and has reported previous experimental work on the application of neutron imaging to measure liquid water distributions in fuel cell apparatus.

Liquid water visualization is of primary interest in two-phase model development and visualization, as well as design optimization. Several different phases of research are envisioned to achieve the ultimate goals summarized in Table 1 below. In general, the long-term object is to visualize the generation and motion of liquid water within the DM with sufficient spatial and temporal resolution to capture the dynamic accumulation and motion of liquid in the DM.

Table 1: Long Term Neutron Imaging Goals of Program

Step/Specifications	Experimental Program Envisioned
Step 1 (this year): Space resolution ~ 150 μm, time resolution 30 Hz	Water quantification and analysis with two different TMC Fuel Cells and Evaluation of Imaging Tools (CCD camera, TMC imaging system, and radiograph with Penn State software system)
Step 2: Space resolution ~ 10-50 μm, time resolution 30 Hz	Computed Tomography and Additional Experimentation to visualization of liquid growth accumulation, and motion in the DM
Step 3: Space resolution ~ 10-50 μm, time resolution 200 Hz	Visualization of two-phase flow dynamics within the DM with enhanced spatial and temporal resolution.

SOFT ERROR ANALYSIS TOOLSET (SEAT) DEVELOPMENT

Participants: V. Narayanan, Prof. of Computer Science and Engineering Dept.
M. J. Irwin, Prof. of Computer Science and Engineering Dept.
K. Ünlü, Prof. of Mechanical and Nuclear Engineering Dept.
Y. Xie, Prof. of Computer Science and Engineering Dept.

S. Çetiner, Ph.D. student at Mechanical and Nuclear Engineering Dept.
V. Degalahal, Ph.D. student at Computer Science and Engineering Dept.
F. Alim, Ph.D. student at Mechanical and Nuclear Engineering Dept.

Services Provided: Neutron Beam Laboratory

Sponsors: Radiation Science and Engineering Center, Department of Computer Science and Engineering

INTRODUCTION

Soft errors, or single event effects (SEE), are transient circuit errors caused due to excess charge carriers induced primarily by external radiation. Radiation, directly or indirectly, may induce localized ionization that can flip the internal values of the memory cells. The major radiation source that causes this temporary malfunction in semiconductor devices is the cosmic rays.

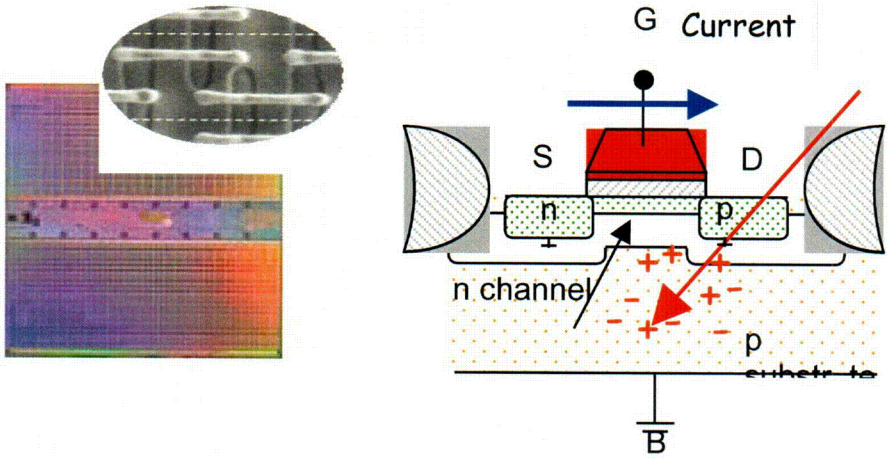


Figure 1. A 65-nm DRAM (left) and a schematic that conceptualizes the soft error phenomenon (right): Electron-hole pairs created through ionization by radiation might get drawn to node terminals before they recombine in the substrate causing a transient glitch in the device node. This temporary pulse might flip the internal state of the memory bit.

Cosmic ray particles have the ability to either toggle the state of memory elements or create unwanted glitches in combinational logic that may be latched by memory elements. As supply voltages reduce and feature sizes become smaller in future technologies, soft error tolerance is considered a significant challenge for designing future electronic systems. For example, a 1 GB memory system based on 64Mbit DRAMs has a combined error rate of 3435 FIT (failure in 10^9 hours of operation) when using single error correction and double error detection. An even higher soft error rate of 4000 FIT was reported for a typical processor with approximately half of the errors affecting the processor core and the rest affecting the cache. Such errors also affect the fast growing FPGA (Field Programmable Gate Array) segment.

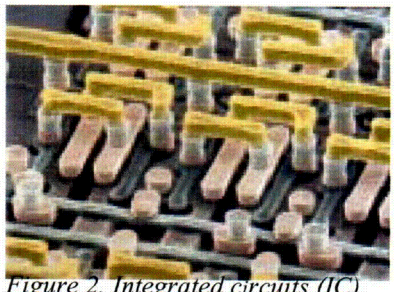


Figure 2. Integrated circuits (IC) are becoming a major component of modern societies.

As earth's atmosphere shields most cosmic ray particles from reaching the ground and charge per circuit node used to be large, SEE on terrestrial devices has not been important until recently. The galactic flux of primary cosmic rays

(mainly consisting of protons) is very large, about 100,000 particles/m²s as compared to the much lower final flux (mainly consisting of neutrons) at sea level of about 360 particles/m²s [1]. Only few of the galactic particles have adequate energy to penetrate the earth's atmosphere. However, with continued scaling of feature sizes and the use of more complex systems, soft errors in terrestrial applications are becoming an increasing concern and have drawn attention since late 1990s.

The issue of SEE was first studied in the context of scaling trends of microelectronics in 1962 [2]. Interestingly, the forecast from this study that the lower limit on supply voltage reduction will be imposed by SEE is shared by a recent work from researchers at Intel [3]. However, most works on radiation effects, since the work in 1962, focused on space applications rather than terrestrial applications.

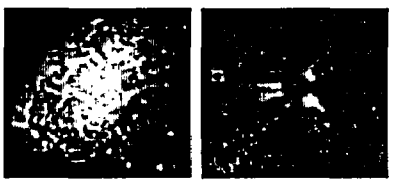
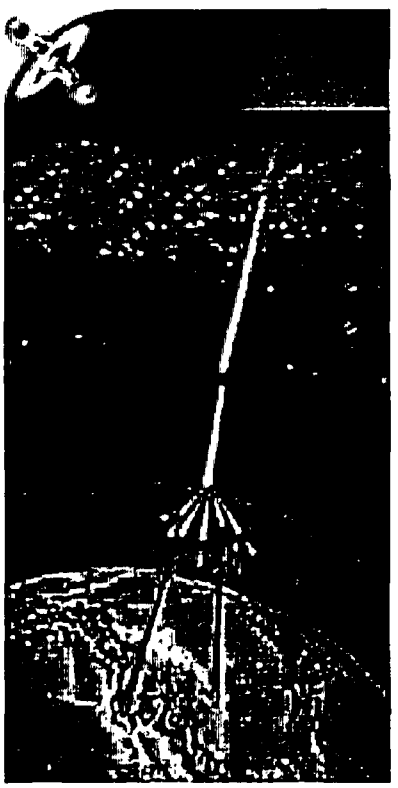


Figure 3. Top: Cosmic rays have two major origins: Primary cosmic rays are produced and accelerated by stellar flares, supernova explosions (left), pulsars, and explosion of galactic nuclei. Solar cosmic rays (right) are the particles in the solar wind originating in the Sun. Bottom: Particles from primary sources travel the space and enter the earth's atmosphere. Fewer than 1% of the primaries can make it to the ground, and they are mostly third- to seventh-generation cascade particles.

There have been various documented failures due to soft errors ranging from memories used in large servers and aircrafts to implantable medical devices like cardiac defibrillators [4]. A widely cited soft error episode involves L2 caches with no error correction or protection that caused Sun Microsystems' flagship servers to crash suddenly and mysteriously [5]. This problem resulted in loss of various customers for Sun Microsystems. More ominous than this failure can be errors in embedded devices such as cardiac defibrillators that are becoming an integral part of our society. As computing systems develop into indispensable part of various critical applications ranging from medical implants to fly-by-wire aircrafts, immunity against soft errors becomes more critical for the society as a whole.

The importance of dealing with the soft error problem can be evidenced by the large number of papers and articles that flooded the scientific community over the last decades. However, most researchers are impeded by access to realistic fault models and real soft error data. This limitation results from confidentiality of soft error data of chips tested by semiconductor companies and the limited access to accelerated soft error testing facilities for academics. Most commercial soft error testing in U.S.A. is performed at the Los Alamos test facility, access to which is expensive and cumbersome due to security clearances required.



THE IMPETUS BEHIND THE SOFT ERROR ANALYSIS TOOLSET (SEAT)

Radiation-induced SEE may seem to be easily solved through techniques such as radiation-hardened processing. These kinds of countermeasures have been traditionally and successfully adopted to remedy radiation effects in space applications. However, they are not suitable for commercial manufacturers of terrestrial devices as many of the solutions consume more power, reduce manufacturability and severely influence IC performance [6]. Even space applications are moving away from the use of radiation hardened process technology. They are using commercial off-the-shelf components that employ soft error protection techniques at software and architecture level for cost and performance reasons. As a result, many researchers have been focusing on employing new soft error countermeasures ranging from process to software levels.

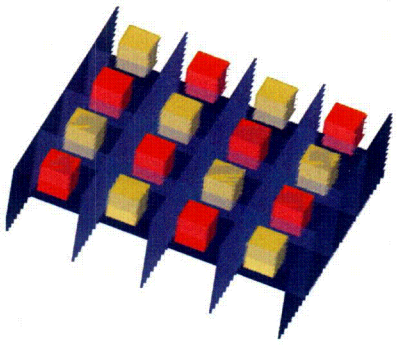


Figure 4. A sample 3D model used in MCNP model. Red cells represent p wells (boron doped), yellow cells represent n wells, and transparent blue silicon. The geometry and the number of cells can be altered wit regards to the device to be modeled. This allows for simulating multiple upsets in adjacent cells caused by a single particle.

Advances in process technology such as adoption of silicon-on-insulator (SOI), elimination of boron-10 impurities are expected to mitigate the soft error problem to a certain extent. However, solutions at higher levels are still essential for reliable operation of the computing system. The lack of fault models that abstract the physical phenomena of soft errors accurately in a fashion that is accessible to computer engineers and the absence of tools that analyze the effectiveness of soft error countermeasures are affecting researchers in their quest for taming the soft error problem.

There is an obvious need for a community resource for researchers and industrial practitioners studying radiation-induced SEE on computing systems. Existing tools either do not address the problem in full extent or they are kept confidential by the sole proprietorship of commercial entities, and therefore are not available to the research community. The SEAT will serve a critical purpose in providing researchers of electrical, computer, information sciences or nuclear origin with an open, modular, flexible yet a comprehensive tool.

The SEAT has emerged as a complementary tool to furnish theoretical foundation to experimental radiation-induced soft error research at Penn State Breazeale Nuclear Reactor by mechanical and nuclear engineering, and computer science and engineering departments. More details can be found in [7] in this annual report. The experiments performed are compiled into an "accelerated soft error testing dataset". The researchers are then able to seek to duplicate these observations by the SEAT or vice versa.

The strength of the SEAT is the fact that it is built upon the combined expertise of computer and nuclear engineers. The SEAT hierarchy starts with modeling the ionization effects of particle strikes on semiconductor devices, and then creates higher-level abstractions of these effects for analysis at the circuit and architecture level. This infrastructure will enable researchers working on circuit, architectural and software countermeasures for soft errors to obtain a better perspective of the physical phenomena, and help them tune their techniques accordingly. If the fault model used at architecture or circuit-level fails to model the SEE accurately, the underlying value of solutions proposed at higher abstractions become meaningless.

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IMPLEMENTATION OF THE SEAT CODE BUNDLE

The SEAT code bundle has a hierarchical structure as shown in Figure 5. Information collected at each level is relayed to one upper level for analysis.

Neutron transport constitutes the basis of the lowest-level analysis of the toolset. The creation of neutron-induced charged particles is simulated at this stage of the analysis. We chose MCNP5 to perform the neutron transport simulation. MCNP5 is a very powerful Monte Carlo code and comes with an extensive set of utilities. Figure 4 shows geometry that we used for the multi-bit SEE analysis in memories. The transparent blue material corresponds to bulk silicon, and red and yellow cubes are boron- and phosphorus-doped p and n wells, respectively.

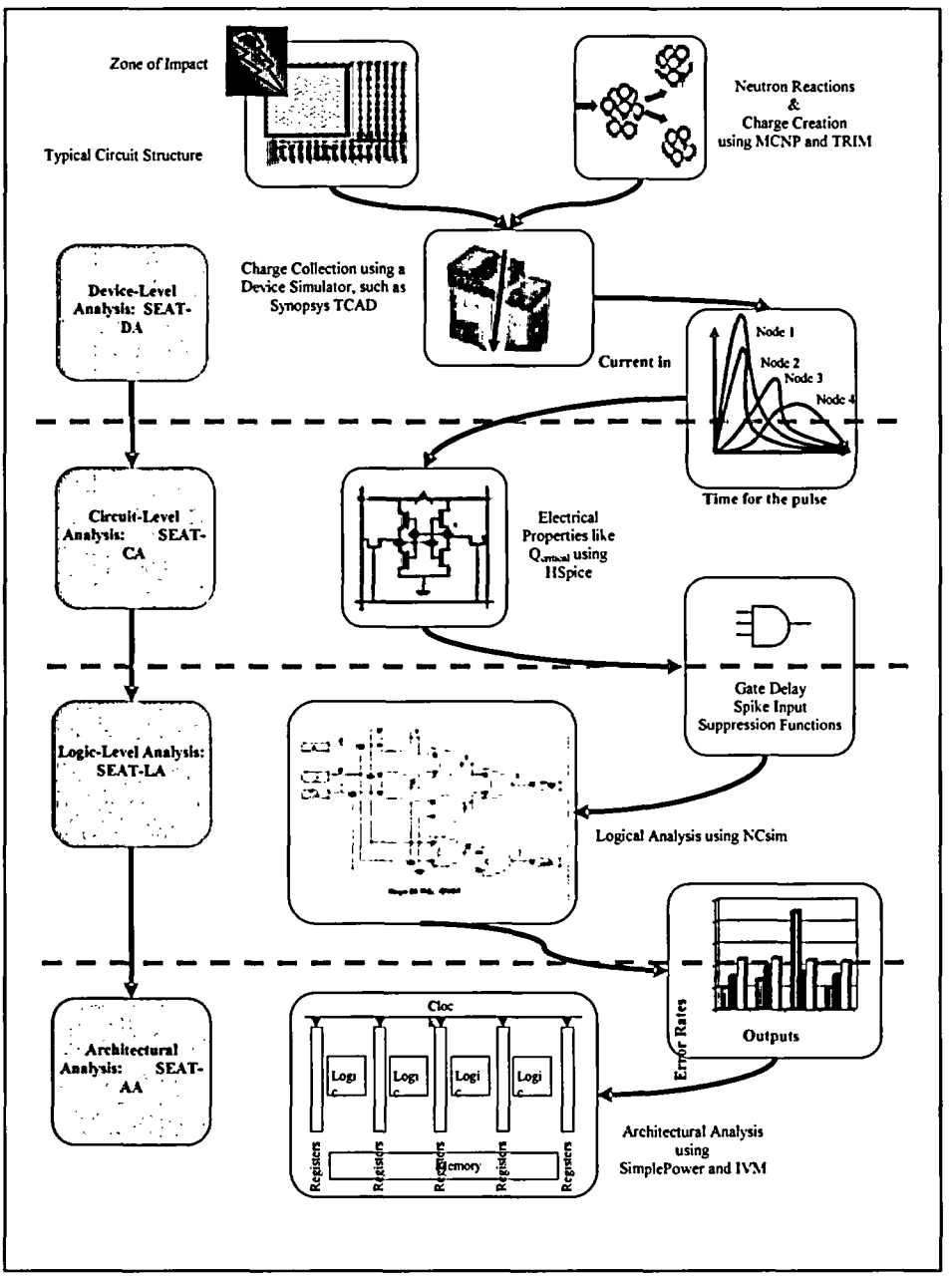

Figure 5. The flow diagram of the SEAT code bundle. Information collected at each level is transferred to the next simulator to be analyzed.

The MCNP output is analyzed and the reactions that ultimately end up in creation of charged particles are collected. These ions are saved into a file in a format that is compatible with the next code, TRIM [8], at that level of analysis.

TRIM is another Monte Carlo code that simulates ion transport in solid media. TRIM accepts 3D ion distribution as input. Since it is given the same geometry as MCNP, it simulates the behavior of ions that come out of the neutron-induced reactions. The analysis of ion tracks gives as to what point in the medium the energy will be deposited. This is a first-order approximation to ionization caused by the charged particle transport, and is known as the Bragg approximation.

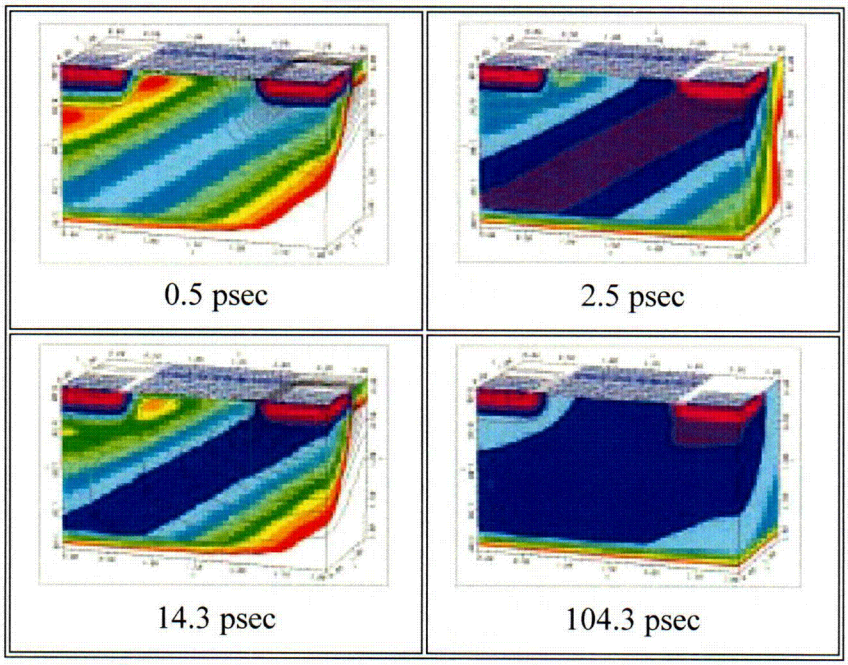

Figure 6. Time evolution of charge dispersion in a transistor node. Contour lines represent equipotential lines under the electric field.

Once the list of ions induced by external radiation and position of charges deposited is obtained, then the simulation of the phenomenon in device level can be performed. Figure 6 shows the output of a sample simulation performed with TCAD. In the figure, color contours represent the electron concentrations, and the line contours correspond to equipotential lines. Ion strike is initialized at time 1 psec. Before the ion strikes, equipotentials are parallel to the junction. The sequence of plots show that the charge column widens by the outward diffusion of carriers. The charge column also pinches off at the junction due to collection of charge from the depletion region. At time 1 psec, the equipotentials begin to extend into the substrate due to the voltage drop along the charge column. After a time the funnel starts to collapse and the drift current starts to decrease as charge is swept away from the depletion region. At 100 psec, the depletion region is effectively restored and only diffusion charge collection occurs.

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CONCLUSIONS AND FUTURE WORK

The SEAT seems to fill a critical need, particularly in research community. With its current stage, it received a great deal of interest from both the academia and industry. We received many positive critiques in a conference that we presented the SEAT the first time [9]. Many industry affiliates stated their interest in the tool.

Even though neutrons account for the majority of the cosmic particles at sea level, the contribution of other particles, particularly protons, become dominant to the soft error problem at higher altitudes. For a more through analysis and more extensive applicability, other particle interactions should also be incorporated into the simulation. At this stage of the tool, we managed to include proton flux in the cosmic rays into the analysis. This, however, does not include nuclear-level interactions of protons with the medium, but it does take into account their direct ionization effect. For better modeling of physics, nuclear interactions of protons with the host nuclei must be accounted for since this dominates proton-related single-event effects.

The problem can be tackled by using medium-, high- and very high-energy intranuclear cascade codes, which simulates particle reactions within the nucleus between the particle and nucleons based on nucleon-to-nucleon cross sections. Addition of a cascade code will extend the capability of MCNP, which, with the current cross section library, can support up to 150-MeV incident neutron energy. Cross sections for incident neutron energies beyond 150 MeV is extrapolated. The nuclear cascade codes, however, can simulate interactions for particle incident energies even beyond 1 GeV.

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NEUTRON IMAGING SYSTEM IMPROVEMENTS

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Services Provided: Neutron Beam Laboratory

Sponsors: DOE- INIE, RSEC and MNE

INTRODUCTION

The growing demand for dynamic neutron imaging (radioscopy), especially for fuel cell research, has placed new requirements on our existing neutron imaging capabilities. These included developing a more efficient means of data acquisition and storage, better post processing techniques, and a more accurate quantification of water present in the radioscopic images. To this end, the neutron imaging team at the Radiation Science and Engineering Center (RSEC) has made several fundamental and very advantageous changes to its equipment and software resources. The following sections describe the recent upgrades to our imaging and post-collection image processing systems.

EQUIPMENT UPGRADES

For many years our dynamic imaging system consisted of an analog camera connected to a computer through an analog-to-digital interface card that allowed the capture of 30 fps images at 640x480 and 8-bit grayscale depth. This system provided a stable foundation to support the development of data capturing and post processing procedures. To meet the requirements for our recent fuel cell research, a "turn-key," completely digital, image acquisition system was added.

Purchased through the company "I-Cubed," the complete system is comprised of a Pentium IV computer system with camera interface card, a Cohu CCD Camera and image capture software. The computer system is exceptional for both storage of the large volumes of digital image data being captured during radioscopy experiments and the running of the in-house developed, post processing and water quantification software. The digital CCD Cohu camera supplied with the system has a 1004x1004 pixel resolution and a 10-bit deep grayscale range. When connected to the computer's interface card, frame rates as high as 30fps are possible. The unique driver set and onboard buffers of the Epix interface card make this possible.

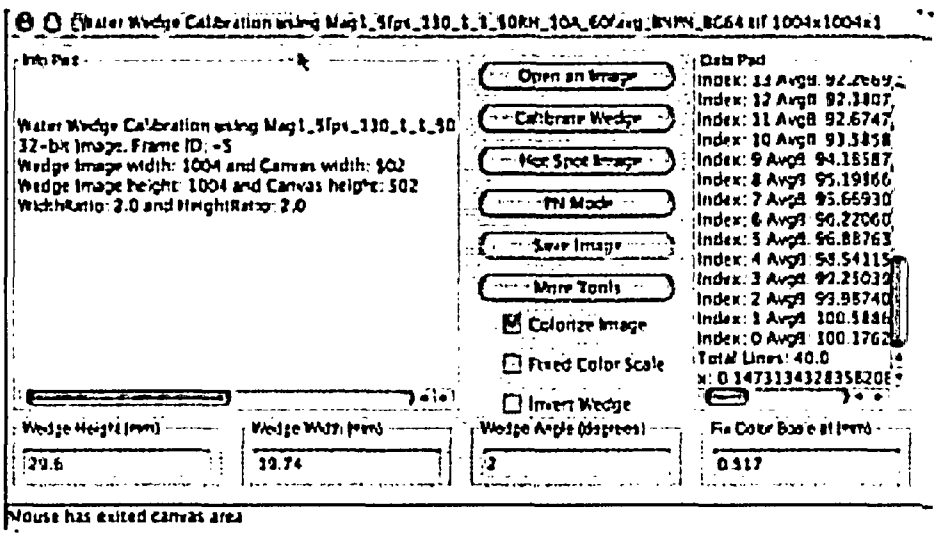
Norpix's Streampix image acquisition software was included with the computer. Image capturing and storage is done in the form of proprietary image stacks called "sequence files," which can then be exported to a variety of formats, most notably TIFF and AVI. All post processing is done in the TIFF format since it a lossless image format and can be read on PC, Macintosh or Unix computers. AVI files are convenient when a qualitative, "real-time" inspection of an object is desired. The saved image sequence file can be converted to the AVI movie format and played back on Quicktime or Windows media player without the need for secondary movie conversion software.

The Streampix software also includes the ability to run user-written plug-ins. This feature allows the synchronization of image capture with external devices through the serial port or external data acquisition cards. Capturing an image along with a pressure or temperature reading is now possible, as well as capturing an image at the request of an external device, such as a rotation table signaling proper test subject alignment.

The decision to use a "turn-key" system was based on the desire to avoid incompatibilities between the various hardware components. An added advantage of the "turn-key" system is the accompanying tech-support, which can troubleshoot problems and provide quick solutions.

POST PROCESSING SOFTWARE UPGRADES

The Penn State neutron imaging team has focused on developing in-house software for data analysis. PSUMagic is the latest incarnation of the PSU Frame Grabber software originally designed for use with the older analog imaging system. With high-speed digital image capture now accomplished through Norpix's Streampix, an earlier version of PSUMagic was modified to enhance its post-processing and water quantification algorithms.



PSU Magic Main Window

Several post-process image enhancement techniques were incorporated to increase the overall image quality and accuracy of the water quantification process.

To account for the random noise in sequential images, the luminance value of corresponding pixels within sequential images can be averaged. This process improves image quality and makes liquid water accumulation and movement more discernible, albeit at the expense of temporal resolution.

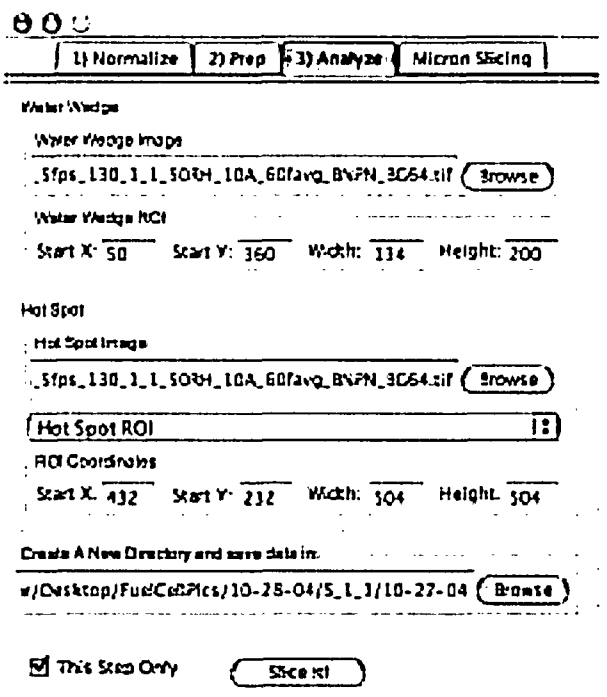
Minor fluctuations (typically <<1%) in the reactor power level are common during experiments, resulting in changes in the neutron beam flux and consequently the corresponding measured pixel luminance values in a captured image. By monitoring a reference location on each image that is recorded, the beam intensity between each frame is determined and the entire image is normalized accordingly. The reference is a static location, such as the fuel cell backing plate, outside the active area where pixel luminance should be theoretically constant throughout the length of an experiment. This procedure is referred to as "Reactor Power Normalization".

The PSU Magic software can correct for variations in the intensity of the neutron beam across the image plane using a beam normalization technique (sometimes called "flat-fielding"). By examining a blank image (only the uninterrupted neutron beam), the average pixel luminance value is determined. The acquired average value is divided by each individual pixel luminance value of the blank image to produce a corresponding correction factor for each pixel. The correction factor matrix is then multiplied by each image recorded during actual experiments to produce a "flattened" image making the initial beam intensity uniform.

Several other image enhancement techniques to improve qualitative analysis have also been added. These are also very useful highlighting water levels in presentations of single images or video clips. These include false colorization of liquid water in the fuel cell to make it more discernible and a technique that produces an image of only liquid water in the cell. This procedure is referred to as "Water Attenuation Map Isolation" or "Water Isolation."

Raw Test Block Image Test Block Image After Post Processing

Many of the aforementioned post processing procedures are used when isolating and quantifying the water present in neutron images. To reduce the users effort when analyzing large numbers of images, a user friendly GUI was included to automate Power Normalization, Flat-Fielding, Water Attenuation Map Isolation and Water Analysis and Colorization.

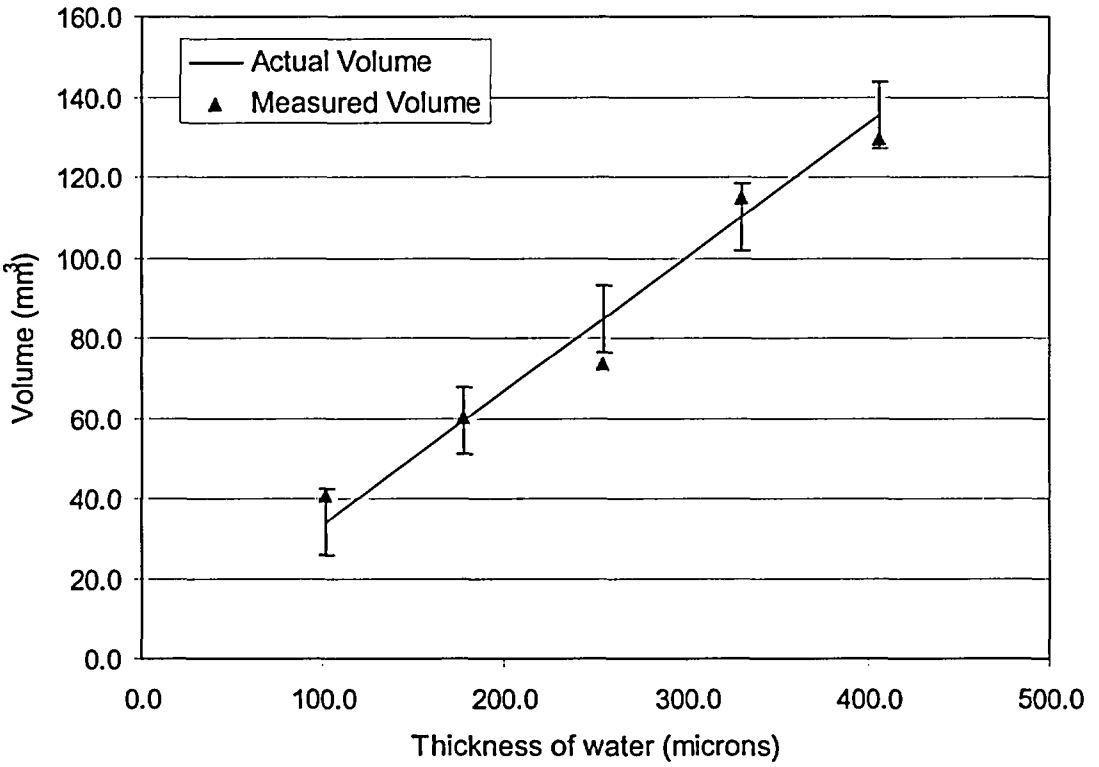


PSU Magic Automation Menu

The ability to store individual images digitally allows for easy post-process analysis including ascertaining pixel luminance values of features in the image, such as water within a fuel cell. Consequently, the determination of water content within a cell as a function of time is attainable by referencing a pre-generated calibration look-up table that correlates water thickness to pixel luminance. This table is generated using a water-filled calibration wedge that duplicates the neutron attenuation and scattering effect of the fuel cell. The wedge is the exact distance from the beam port aperture as the fuel cell to ensure the equal beam intensity and hence measured attenuation as the fuel cell.

The wedge contains a water-filled channel of continuously varying thickness. The steady and gradual decrease in pixel luminance from the bottom to top of the wedge is representative of the increasing water thickness level within the wedge. This luminance data can then be referenced to assign water thickness values to individual areas within the cell or the entire cell as a whole. The mass and volume of water in the cell can then be computed for finite instances or as a varying function of time This method works well in this application because the water thickness are at most 1 mm, and they are typically less than 250 μm. Thus, there are essentially no multiple neutron scatters.

The water quantification procedure was confirmed using an aluminum block milled with channels of known width, height and thickness, filled with water and exposed to the neutron beam where radioscopic images were captured. The post processing and water quantification procedures were applied and the measured values showed good agreement with the theoretical values.



Test Block Water Attenuation Image

FUTURE INNOVATIONS

Refinement of water quantification in neutron imaging is ongoing. Future experiments will determine the minimum thickness of water the system can see and measure. The look-up table method of analysis will be replaced with a fitted equation providing more accuracy.

A Neutron Computed Tomography (CT) system is being developed to compliment our neutron imaging capabilities. The CT system will make use of recent software developments such as the cross sectional reconstruction software, Octopus, and the volume 3-D image generation software, VGStudio Max.

NEUTRON BEAM CHARACTERIZATION OF THE BREAZEALE NUCLEAR REACTOR AT THE PENNSYLVANIA STATE UNIVERSITY, RSEC

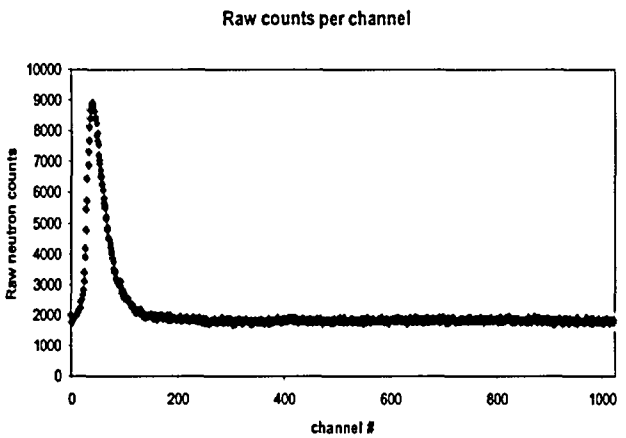
Participants: J. S. Brenizer, Nuclear Engineering Program Chair and Professor
K. Ünlü, Professor

C. Trivelpiece, Graduate Student

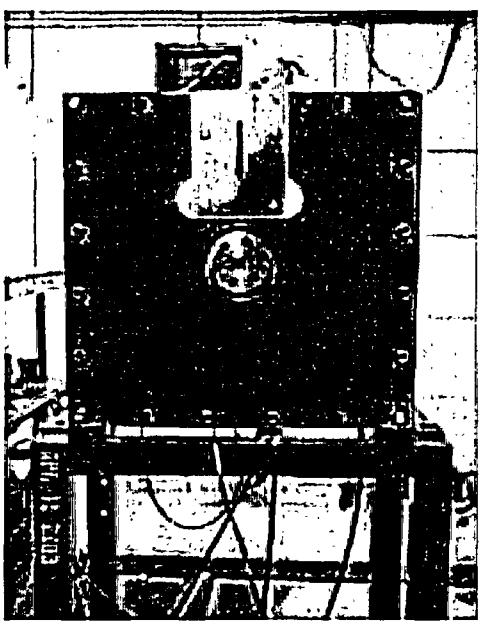
Services Provided: Neutron Beam Laboratory

Sponsor: Department of Energy, Innovations in Nuclear Infrastructure and Education (INIE)

Neutron beams are used in a variety of experimental methods at research reactors all across the United States. Such applications include: neutron radiography and tomography, neutron depth profiling, neutron diffraction, etc. The aforementioned techniques employ neutron interactions, which are characterized by energy dependent cross sections. Accordingly, information characterizing the energy spectrum of these neutron beams is useful.



The current method being used for neutron spectroscopy at the Breazeale Nuclear Reactor is a time-of-flight (TOF) method using a slow neutron chopper that was brought from Cornell University, Ward Center for Nuclear Sciences. The TOF technique is based on measuring the time it takes neutrons to travel a predetermined distance. For this experiment, we measure the amount of time it takes for neutrons to travel from the aperture of the slow neutron chopper itself (Figure 1), to a lithium loaded glass detector. When the reactor is at power, a collimated neutron beam is incident on the chopper slit that can be seen in Figure 1. Inside the chopper device, a disk rotates and essentially fragments the incident neutron beam. Every rotation of the disk triggers an optical sensor that signals the beginning of the TOF measurement. The TOF measurement is completed for given neutrons when neutrons enter the detector and produce pulses. A computer program is used that provides the ability to measure multiple channels (corresponding to multiple neutron flight times) for each rotation of the chopper disk. The neutron spectrum is obtained from a multi-channel scaler (MCS) and each channel in the collected spectrum corresponds to specific neutron energy. Figure 2 is a typical energy spectrum collected using the current experimental setup. The neutron energy spectrum detectable with this particular system ranges from 0 ~ 0.3 eV.



Currently, work is being done to make the slow neutron chopper system portable so that the system can be used at other research reactors. The original chopper setup consisted of the chopper, a collimating tube, detector and detector shielding. Also, multiple nuclear instrumentation modules (NIM) and bins needed for pulse processing and data analysis.

Recently, equipment was purchased to accomplish the goal of making the analysis portion of the chopper system portable. The new equipment includes:

- Canberra Portable Bin/Power Supply (Model 1000)
- Canberra Multiport II MCA/MCS
- Canberra High Voltage Power Supply (Model 3102D)
- Dell Latitude D600 Notebook PC

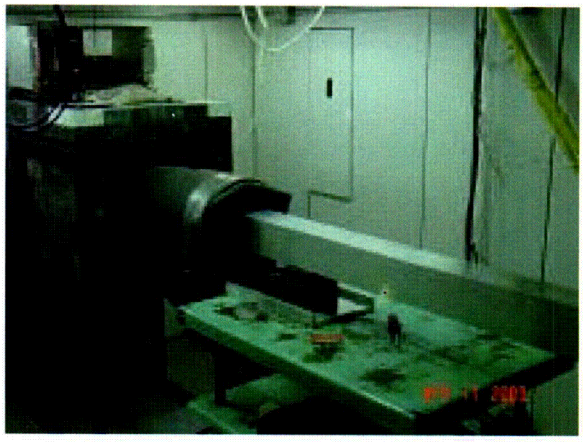


Figure 3: Neutron collimator tube and detector shielding

Two ORTEC instrumentation modules (Spectroscopy Amplifier and an SCA) are used in the signal processing; however, these modules were also used in the original setup. The original MCS was located on a PCI card and required a computer with an open PCI slot for operation. The Multiport II MCA/MCS device uses an internal analog-to-digital converter (ADC) and a USB connection to connect to the Dell notebook, eliminating the need for a PCI card based MCS as well as a desktop computer with an open PCI slot. The Multiport II works like any other nuclear instrumentation module in that it is compatible with any NIM bin. This compatibility, coupled with the USB connection capability, makes the Multiport II one of the key pieces in making the slow neutron chopper system portable.

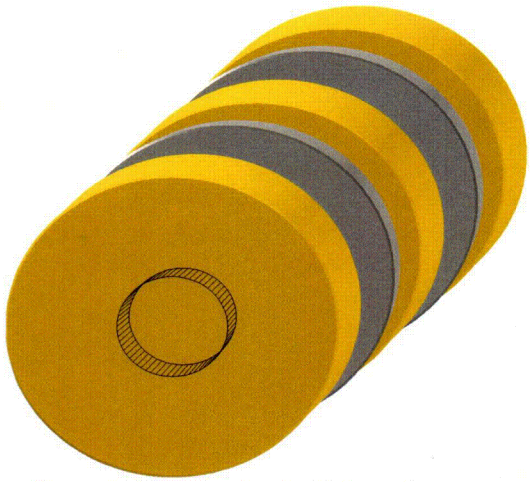


Figure 4: Proposed polyethylene / borated aluminum shielding annuli

The design of the experimental setup (slow neutron chopper, collimator tube, detector and shielding) must also be redesigned in order to make the slow neutron chopper system portable. To accomplish the goal of being able to ship the system to other research reactors, system components must disassemble and reassemble with ease, and still meet their experimental needs. Currently, the slow neutron chopper is mounted on a stand which keeps the chopper slit at a constant height corresponding to the height of the neutron beam. The collimator and the detector (w/ shielding) are aligned so that the slit and the detector are at the same height. The original system will be redesigned to give the components adjustable heights, so that the system can be used in different nuclear research reactors. The distance from the front of the collimator tube to the back of the detector shielding is approximately 2.5 meters (Figure 3). This length poses a problem when considering shipping methods. The collimator tube will be redesigned into sections, probably three, that can be easily attached together while keeping the strict alignment tolerances needed for this experiment. The detector shielding must also be redesigned for shipping purposes. One idea being discussed involves machining polyethylene and borated aluminum annuli, in which the detector will be placed (Figure 4). The polyethylene will be wrapped with boroflex to provide additional neutron shielding. Shipping cases and packing material will be purchased to complete this stage of the project.

To date, two experimental runs have been made at a reactor power of 850 kW. The first run was made with the original system (desktop PC, PCI based MCS card) to ensure that the system was properly aligned in the beam. Upon completion of this run, the detector was immediately connected to the new equipment (Multiport II, Dell notebook), and a second neutron energy spectrum was collected. The two spectra were compared and found to be similar, implying that the new equipment is suitable for use in this experiment. Experimental runs at different power levels will be made in the near future.

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As mentioned earlier, the detectable neutron energy range for the slow neutron chopper system is 0 ~ 0.3 eV. It is desirable to measure the higher end of the neutron beam energy spectrum. An ORTEC Model 525-780 Helium-3 Neutron Spectrometer has been ordered which will allow neutron energy spectrum measurements of both thermal and fast neutrons. This spectrometer utilizes the $^{3}He(n,p)^{3}H$ reaction. The incident neutron energy is determined by measuring the energies of the proton and the triton which are produced during the reaction. Shipping cases and materials will also be purchased so the helium-3 spectrometer can be shipped along with the slow neutron chopper system to characterize the energy spectrum of other neutron beam facilities.

Progress is being made to make the neutron beam characterization equipment portable, and extend the detectable energy range of the current setup. When completed, the slow neutron chopper system, combined with the helium-3 spectrometer, will make a useful tool for characterizing the energy spectrum of neutron beams at many research reactors across the United States.

TESTING NEUTRON-INDUCED SOFT ERRORS IN SEMICONDUCTOR MEMORIES

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S. M. Çetiner, Ph.D. Student

Services Provided: Neutron Beam Laboratory

Sponsor: DOE, INIE, Big-Ten Consortium Mini Grant Program

INTRODUCTION

Soft errors are transient circuit errors caused due to excess charge carriers induced primarily by external radiations. Radiation directly or indirectly induces localized ionization that can flip the internal values of the memory cells. Our current work tries to characterize the soft error susceptibility for different memory chips working at different technology node and operating voltage.

BACKGROUND AND RELATED WORK

Advances in VLSI technology have ensured the availability of high performance electronics for a variety of applications. The applications include consumer electronics like cellular phones and HDTVs; automotive electronics like those used in drive-by-wire vehicles, and million dollar servers used for storing and processing sensitive and critical data. These varied applications require not only higher throughput but also dependability. Even if a microprocessor is shipped without any design errors or manufacturing defects, unstable environmental conditions can generate temporary hardware failures. These failures, called *transient faults*, cause the processor to malfunction during operation time. The major sources of transient faults are electromagnetic interference, power jitter, alpha particles, and cosmic rays. Studies in [1, 2] have shown that a vast majority of detected errors originate from transient faults. Even a single-bit error may eventually lead to a computation failure. Therefore, managing the soft errors is a critical problem to solve in fully realizing dependable computing.

Soft error rate (SER) testing of devices has been performed for both neutron and alpha particles. Beam 30L of Weapon Neutron Research at the Los Alamos National Laboratory is a JEDEC prescribed test beam for soft errors, and is the only one of its kind. This beam is highly stable and it closely replicates the energy spectrum of terrestrial neutrons in the 2-800 MeV range while providing a very high neutron flux. The SER testing reported in literature recently were performed at this facility [4, 5]. However, the beam availability is limited. Alternatively in the past, experiments were carried out with alpha particles originating from ^{238}Th foil on 0.25 μm-generation SRAMs [7]. Elimination of borophosphosilicate glass (BPSG) and ^{10}B from the process flow in the 180-nm generation has made the low-energy (<1 MeV) neutron SER negligible [3]. High-energy (1-1000 MeV) neutrons often dominate SER in advanced CMOS logic and memories. Hence, the need for accessible neutron testing facilities is critical for design of the next generation semiconductor devices.

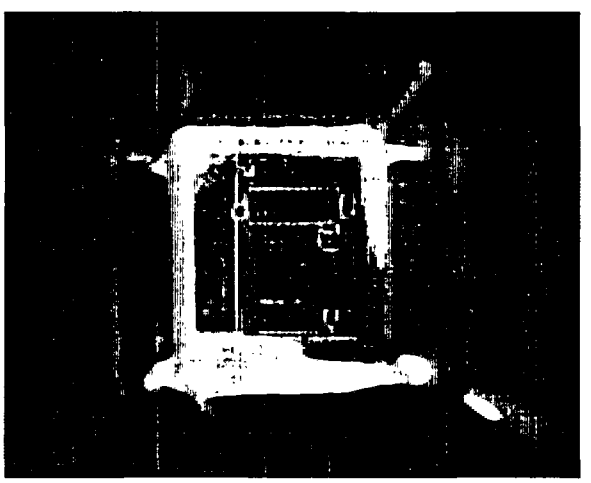

Figure 1. Test chip as seen from the narrow opening in the polyethylene/lead shield.

This study intends to observe the effect of ^{10}B and high energy neutrons on soft error rate. In order to investigate the effect of Boron-10 on SER, a thermal neutron beam is used. For high-energy neutron testing, we intend to use the fast neutrons available near the reactor core by inserting a test circuit into a stand-up pipe adjacent to the reactor core face. This setup is shown in Figure 2.

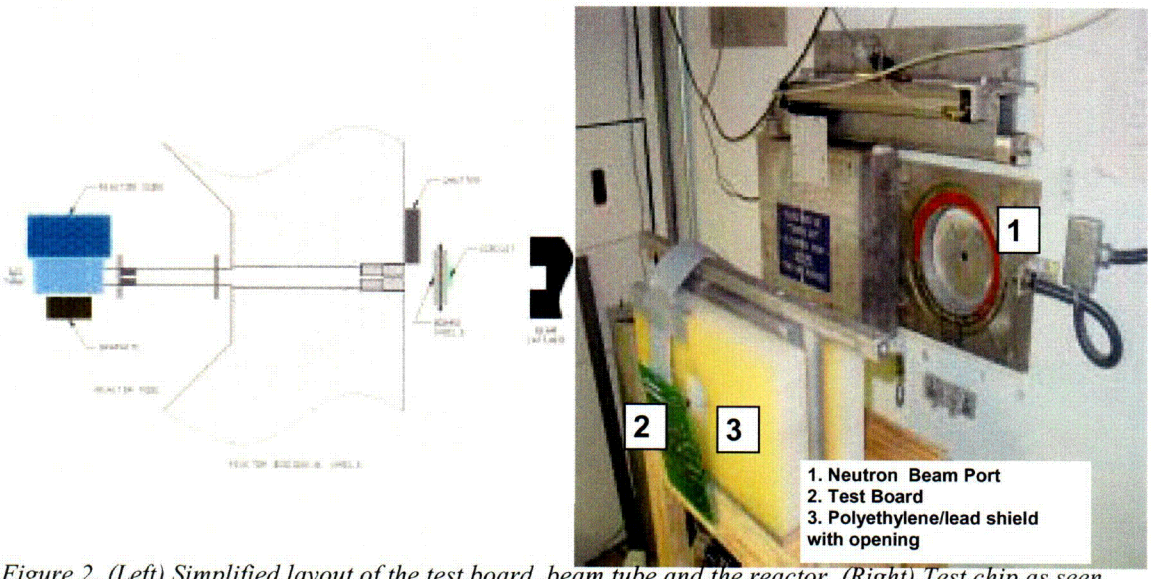

Figure 2. (Left) Simplified layout of the test board, beam tube and the reactor. (Right) Test chip as seen from the narrow opening in the polyethylene/lead shield.

EXPERIMENTAL SETUP AND RESULTS

Penn State Breazeale Nuclear Reactor was used as the neutron source in the experiments. The maximum rated power of the reactor is 1 MW in the continuous mode, and 2000 MW in the pulse mode. The reactor power is adjusted from 10 W to 1MW observe the soft error rate dependence on neutron flux. No pulse-mode operation has been performed. Figure 1 and 2 show the test chip and the experimental setup.

For the beam port that was used in the experiments, the beam tube looks at the D_2O tank to get a well-thermalized beam. The average thermal flux at the exit of the beam port is about 3×10^7 neutrons/cm^{2}sec. The high neutron flux allows for accelerated testing of the phenomenon.

The experimental setup consists of a custom board interfaced with a computer through a GPIB card (from National Instruments). The board itself has off-the-shelf SRAM memory chips. The board is controlled through a LabVIEW interface. The controlling application consists of simple routines to read and write a user specified value across the whole memory. During the readout, it compares the written value to the value in each address.

The circuit board is secured in the beam cave, and connected to a PC outside using a 25-ft cable. This configuration allowed for continuous read-write, and for changing the operating conditions without interrupting the experiment.

The selected section of the board is tested on-line multiple times in the actual setup before the reactor is started. The board is exposed to neutron flux after the reactor reaches the stable power level.

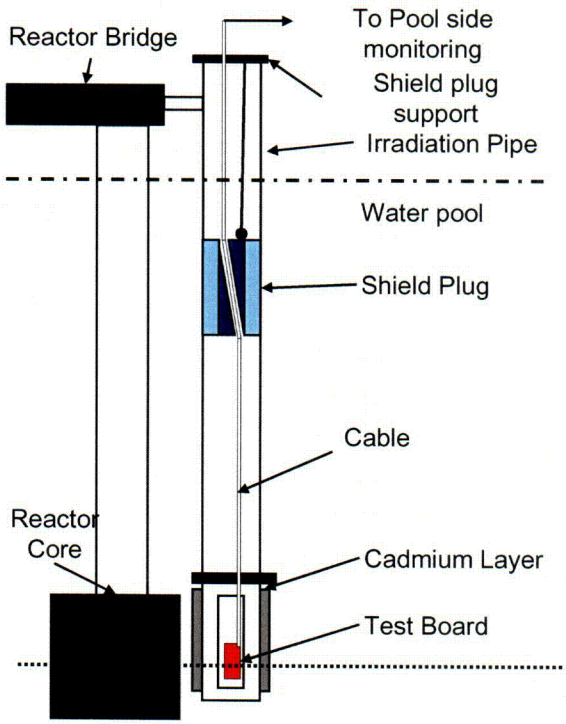

Figure 3. Fast neutron test setup near the reactor core.

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As mentioned earlier, the neutron flux around the reactor core is much higher than that at the neutron beam ports. Therefore, the circuit board will also be placed by the periphery of the reactor core via a vertical standpipe in order to observe the effect of fast neutrons on soft error rate. A schematic drawing of fast neutron irradiation facility at PSBR is shown in Figure 3. The fast neutron flux at the core boundary is 5×10^{12} neutrons/cm^{2}sec, and thermal flux is 1.3×10^{13} neutrons/cm^{2}sec at 1MW steady state reactor operation. The reactor can be pulsed for a very short duration of time, around 10 milli-sec at its Full-Width Half-Maximum, at which it generates a fast flux of about 1×10^{16} neutrons/cm^{2}sec at the core periphery. This amounts to about a ten order of magnitude increase in the fast flux. The time duration is very limited, yet the amount of fast flux is immense. The test circuits will be let inside the standpipe and the reading will be taken. In addition, the walls of the pipe will be covered with cadmium. Cadmium will absorb the thermal component of the flux so that the board is affected only by fast neutrons.

RESULTS AND DISCUSSION

The setup described in this report allows for accelerated neutron testing of semiconductor memory devices. Currently, one memory chip from Cypress Semiconductor was tested across multiple runs. The chip is rated to operate at 5V, but found to operate as low as 3V. We found the chip to have 15 errors after testing for one hour at 3V, but had only 2 errors at 5V for the same time period. Similar experiments were also conducted using a Toshiba Chips memory. This confirms the exponential dependence of soft error rate on device operating voltage as pointed out by several authors before [7]. Table 1 presents the details from these experiments.

Table 1. Preliminary Accelerated Soft Error Testing Data

Chip	Operating Voltage	SER/h
CY7C128A-20PC, 16 kbits	5V	2
	3V	15
TC554001AFT7L. 4 Mbits	5V	57
	4V	638

FUTURE WORK

This report briefly summarizes the first phase of the study that focused only on the effect of ^{10}B fission caused by thermal neutron absorption on soft error rate. The elimination of BPSG layer in new device technologies and considerable reduction of ^{10}B content in the p-dopant significantly dropped the contribution of boron fission as a source of soft error. Therefore, for younger-generation technologies, one needs to take into account the high-energy neutron impact on device operation for proper soft error rate analysis.

In the later phase, the circuit will be placed by the periphery of the reactor core in order to observe the effect of fast neutrons on soft error rate. The fast neutron flux at the core boundary is 5×10^{12} neutrons/cm^{2}sec, and thermal flux 1.3×10^{13} neutrons/cm^{2}sec at 1-MW steady state reactor operation.

The reactor can be pulsed for a very short duration of time, around 10 msec at FWHM, at which it generates a fast flux of about 1×10^{16} neutrons/cm^{2}sec at the core periphery. This amounts to about a ten order of magnitude increase in the fast flux. The time duration is very limited, yet the amount of fast flux is immense. That might also reduce the experiment times significantly and help perform more tests with various technologies and designs.

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NEUTRON ACTIVATION ANALYSIS OF ABSOLUTELY-DATED TREE RINGS

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Sponsors: Cornell University, NSF, and RSEC

INTRODUCTION

The Dendrochronology project taking place at the Breazeale Nuclear Reactor is a search for heightened gold concentration in tree rings with the use of Instrumental Neutron Activation Analysis (INAA). The usefulness of this study lies in the environmental and climactic history that can be deduced from the data. Large amounts of stratospheric sulfur from volcanic eruptions, forest fires or industrial pollution can stress trees and result in larger heavy ion uptake. We are focusing on gold uptake because of its suitability to INAA. In addition, climate cycles over 10s of years can be identified and correlated with such well-known cycles as the El Nino Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO). The current climatological record recording these cycles only exists for the past 100-150 years. This relatively short record makes Earth's climate cycles and effects like Global Warming difficult to understand. A correlation with ion uptake in tree rings would allow us to extend the climatological record back thousands of years.

PSU NAA FACILITY

In the past year, the INAA facility was completed at the Breazeale Nuclear Reactor. This includes installing two Dry Irradiation Tubes (DT) in the reactor core, getting the Automatic Sample Handling System (ASHS) up and running, setting up the analysis system with a High-Purity Germanium (HpGe) Detector, a Digital Spectrum Analyzer and Genie-2000 software, and doing the flux measurements necessary to identify flux peak area for sample irradiation positions. Nearly 400 tree ring samples have been analyzed from a tree which grew in Turkey between the years 1473 and 1980 A.D. The tree rings that have been analyzed so far are from the years 1600 – 1980 A.D. We will first complete the analysis of this tree (1473-1980) and continue with a tree from the same region and covering similar time period.

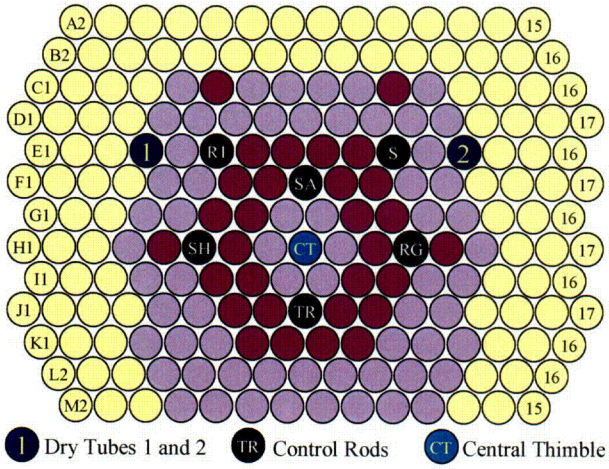

Figure 1. The Dry Tubes occupy positions E4 and E13 in the reactor core.

The Dry Tubes

Two Dry Irradiation Tubes (DT) were installed in the reactor core for irradiation of NAA samples. The DT's occupy approximately symmetric positions within the core, as shown in Figure 1. The bottom of the DTs was designed to be identical to the bottom fuel rod tips and fit into the bottom grid plate. The height of the DTs are approximately 21 feet and bend to 6 inches off the centerline approximately one third of the way up. This allows for samples to be pulled out of the core while they decay but maintain a depth of 14 feet of water as a radiological shield.

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Flux measurements were performed in the DTs at 10 W, 800 kW and 1 MW show that the height of the flux peak is strongly dependent on the position of the control rods but fairly independent of core position within the reactor pool. Measurements were done both in the center of the reactor pool position and coupled core-D_2O tank position. The peak flux at 1 MW was approximately 1.5 x 10^{13} n/cm^2/s with DT1 being consistently slightly higher than DT2. The flux measured inside the polyethylene vials used for wood irradiations is approximately 1.2 x 10^{13} n/cm^2/s with the difference presumably the position of polyethylene vials and possibly from moderation by the polyethylene vial.

The Automatic Sample Handling System (ASHS)

The Automatic Sample Handling System (ASHS) brought from Cornell University, Ward Center for Nuclear Sciences by Dr. Ünlü was installed and tested at Penn State, RSEC. Batch programming files have been written specifically for the Dendrochronology project and for general usage. This allows the user to define the number of samples to be run in the ASHS in sequence and the amount of time that they are to be counted. Special presets can be used, for example real time vs. live time and files can be automatically named and analyzed according to user specified values. The ASHS holds up to 90 samples at one time, allowing for a consistent through put of sample especially useful for such an extensive study as the Dendrochronology project. A close-up picture of ASHS is shown in Figure 2.

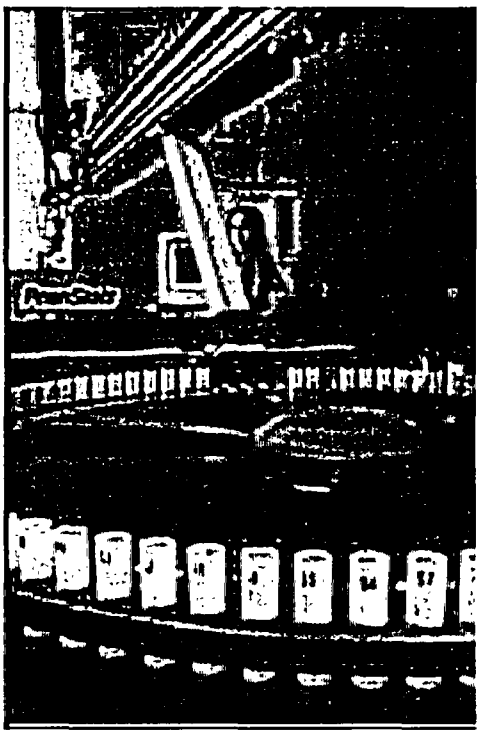

Figure 2. A close up picture of ASHA showing sample tray and robot arm.

HpGe Detector

A new HpGe detector was purchased, allowing the former HpGe detector associated with the Dendrochronology project to be dedicated to teaching and demonstrations. The new HpGe detector has a 36% relative efficiency and 1.8 keV resolution at the higher energy cobalt peak (1332 keV). This has allowed for more accurate isotope identification and area calculations. The detector is surrounded by 3000 lbs of pre-WWII lead bricks to block out environmental background radiation.

Data Analysis

Before irradiating wood samples, the natural radioactivity of the wood should be considered. In order to find the typical isotopes found in un-irradiated wood, and how their abundance differed in different tree rings, approximately 30 tree ring samples were analyzed. The samples that analyzed are from the years 1940-1968 and they are from a tree which grew in Turkey between 1628 and 1998. This measurement period corresponds to the heaviest years of nuclear weapons testing. Consistently the following isotopes were identified in tree samples: Ac^{228}, Ra^{223}, U^{235},Bi^{214} and Pa^{234}.

Recent samples that have been analyzed since the inclusion of the new irradiation facilities in the Breazeale Nuclear Reactor are from a Turkish pine tree and range in date from 1600 to 1980. The average isotope concentrations differ slightly from another Turkish tree which was analyzed previously. A comparison of average concentrations of some isotopes for these trees is given in Table 1. The smaller quantity of Gold in the tree samples requires long irradiations or higher neutron fluences. At RSEC, the tree samples are irradiated at 4MW-hours for each batch of runs. In comparison, typical irradiations of tree samples were 1.2 MW-hours at Cornell University. This more powerful irradiation has allowed for the identification of a new isotope, La-139, which has promising qualities as an indicator of biological stress.

Table 1: Average concentrations of isotopes in two Turkish trees spanning the years 1650 to 1980. The tree CTUCAT14C was analyzed recently at Penn State. CTUKLK10B was analyzed previously at Cornell University. Differences may be due to different uptake properties of the two trees or different regional environmental stresses. Concentrations are in parts per million.

Isotope	CTUCAT14C	CTUKLK10B
Na-23	39.85	52.46
K-41	20.34	21.81
Mn-55	23.69	13.29
Zn-67	1.78	1.72
La-139	.019	N/A
Au-198	.0055	.0078

The chronology of data from the samples recently analyzed is also promising. The data shows a clearly defined base continuum in the isotopes that will behave chemically as salts in the tree, especially including Sodium, Potassium and Bromine. This continuum indicates a steep rise around the late eighteenth century that may be due to increased industrialization, metabolism with in the tree or large time-scale climate cycles. Any of the three possible causes for this increase in background would be an important indicator for future studies. All identified isotopes show very strong peaks (as much as an order of magnitude higher) on top of the background continuum (see Figure 3). The peaks are very consistent among the salt-like isotopes and slightly different for the heavier, non-reactive elements like gold. This may be a result of active transport within the tree of chemicals that take part in the biological processes of the tree. Gold, on the other hand, is inactive and expected to have no active transport and very little passive transport across tree rings, making it ideal for this study. Three example isotopes are shown in Figure 3. Potassium, Zinc and Bromine behave similarly to Sodium. The data we are acquiring now is from another tree that grew in the same region of Turkey and covers the similar time period. We will be looking same trends for this tree in order to verify our previous observations.

CONCLUSIONS

The tree samples that are currently being analyzed have great promise as an indicator of major environmental events in addition to climatic change and plant uptake properties. In particular, the comparison of Gold uptake properties with that of the salts should reveal which effects are due to tree biology and which are due to external stresses. The next immediate goal is to complete the analysis of several trees and make a correlation with environmental effects and the ion uptake behavior of trees.

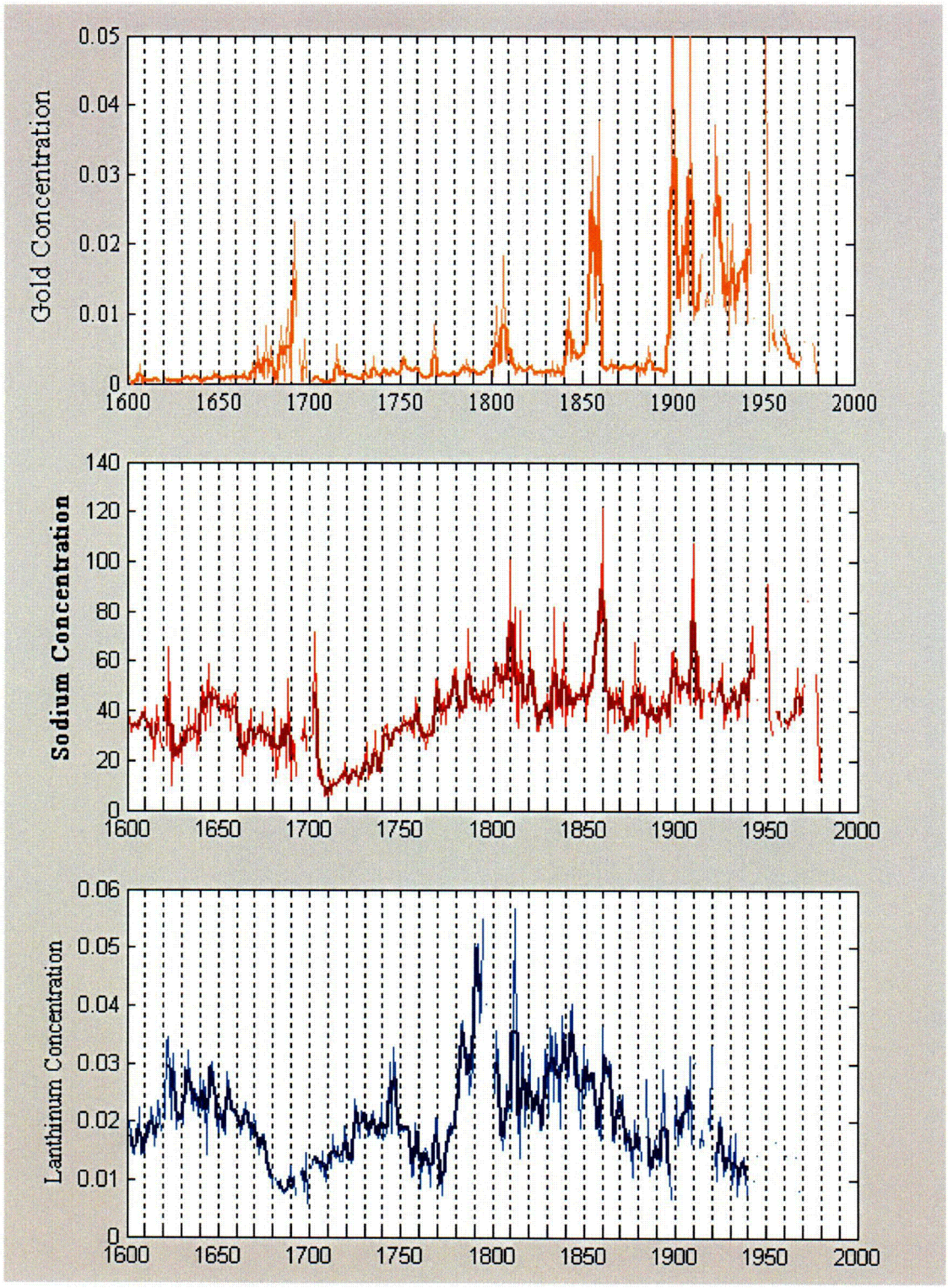

Figure 3. Gold, Sodium and Lanthanum concentrations in the tree sample CTUCAT14C that grew in Turkey between 1600 to 1980. The concentrations are in parts per million.

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TIME-OF-FLIGHT NEURON DEPTH PROFILING (TOF NDP) AT PENN STATE BREAZEALE NUCLEAR REACTOR

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Services Provided: Neutron Beam Laboratory

Sponsor: U.S. Department of Energy, under Nuclear Engineering Education Research (NEER) grant

INTRODUCTION

Neutron Depth Profiling (NDP) is a near-surface analysis technique to measure the spatial distribution of certain isotopes of technological importance in any substrate. The NDP technique was originally developed by Ziegler et al [1, 2] in 1972, and later thoroughly investigated by Biersack et al [3]. The basis of NDP is the irradiation of a sample with thermal or sub-thermal neutrons and the subsequent release of charged particles due to neutron induced exoergic charged particle reactions. Neutrons interact with the nuclei of isotopes ^{10}B, ^{3}He, ^{6}Li, ^{7}Be and ^{22}Na etc, and release mono energetic charged particles, e.g. alpha particles or protons, and recoil atoms. Table 1 gives a detailed listing of other relevant NDP reactions.

Table 1. Useful NDP Reactions

Element	Reaction	Abundance (%)	Target Halflife	Energy of Emitted Particles (keV)		C. Section (barns)	Detection Limit[§] (atoms/cm^2)
He	$^{3}He (n, p) ^{3}H$	0.00014	stable	572	191	533	1.01×10^{14}
Li	$^{6}Li (n, \alpha) ^{3}H$	7.5	stable	2055	2727	940	5.71×10^{14}
Be*	$^{7}Be (n, p) ^{7}Li$	$[2.5 \times 10^{14}]^{\dagger}$	53 d	1438	207	48000	1.12×10^{13}
B	$^{10}B (n, \alpha) ^{7}Li$	19.9	stable	1472	840	3837	1.40×10^{14}
N	$^{14}N (n, p) ^{14}C$	99.6	stable	584	42	1.83	2.93×10^{17}
O	$^{17}O (n, \alpha) ^{14}C$	0.038	stable	1413	404	0.24	2.24×10^{18}
Na*	$^{22}Na (n, p) ^{22}Ne$	$[4.4 \times 10^{15}]^{\dagger}$	2.6 y	2247	103	31000	1.73×10^{13}
S	$^{33}S (n, \alpha) ^{30}Si$	0.75	stable	3081	411	0.19	2.83×10^{18}
Cl	$^{35}Cl (n, p) ^{35}S$	75.8	stable	598	17	0.49	1.10×10^{18}
K	$^{40}K (n, p) ^{40}Ar$	0.012	stable	2231	56	4.4	1.22×10^{17}
Ni*	$^{59}Ni (n, \alpha) ^{56}Fe$	$[1.3 \times 10^{20}]^{\dagger}$	80,000 y	4757	340	12.3	4.37×10^{16}

The charged particles travel outward and lose energy by numerous interactions with the electrons of the host matrix. Measuring the residual energy of the charged particles or recoil atoms and knowing the stopping power of the host matrix allow for the determination of the depth profile of the isotope of interest inside the matrix. The reader is recommended to refer K. Ünlü et al [4-8] for a comprehensive discussion.

PRINCIPLES OF THE TOF NDP

In conventional NDP, the residual energies of charged particles are measured directly by using silicon surface barrier, PIPS, or silicon PIN photodiode detectors. However, because of the physics, there is an error inherent in the measurement process. Conventional semiconductor detectors employ a dead layer at the entrance of the active area. The energy transfer in this layer brings statistical uncertainty to the energies of the charged particles, which are created at single energies and only have a distribution because of the thickness of the material of interest.

In TOF NDP, however, the residual energies of charged particles are not measured directly, but instead it is deduced based on the time-of-flight measurement spectrum.

The time-of-flight information of each particle is obtained from the time difference between the pulses generated by the start and stop detectors. The start detector is triggered by electrons that are sprayed out of the surface of the sample as a charge particle leaves the surface. This is almost a spontaneous process. However, these electrons are ejected from the surface with very small energies and therefore they need to be accelerated for efficient signal processing.

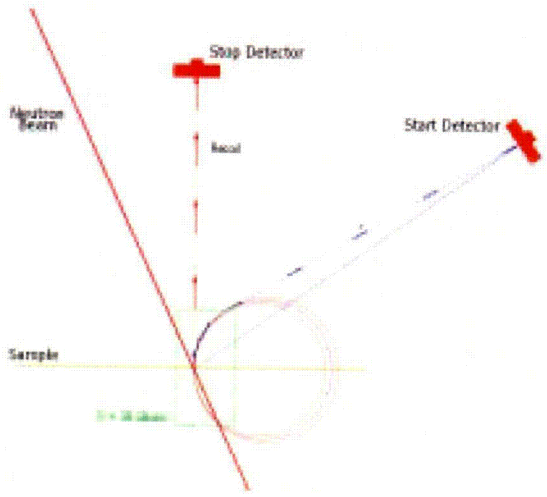

Figure 1. Simplified schematics of the TOF NDP experimental setup

Figure 2. Very fine-meshed sieves are manufactured through a process called electroform meshing.

An electrical field on the path of the particles accelerates electrons. The field is created between the sample plate and a specially manufactured sieve as seen on Figure 2. The micro-mesh structure on the sieves behaves both as a permeable anode surface and filter that eliminates electrons that move off the line of sight. The potential difference between the sample plate and the sieve, which we call "acceleration region", causes an electron to achieve very high velocities because of its miniscule mass. A conceptual schematics of the TOF NDP setup is shown in Figure 1.

An electromagnet steers electrons onto the start detector. Since the mass of electron is small, the amount of magnetic field required is also very limited. This allows for selective particle transfer, i.e. focusing electrons onto the start detector and letting recoils, proton or alphas go directly at the stop detector.

The signals generated by the two multi-channel plate (MCP) detectors have very high precision timing information. These signals are fed into two fast-timing amplifiers that provide time discrimination. Originally, the signals that come out of the MCP's are current pulses. The output of the time discriminator becomes voltage pulses and also reshaped in order to make them compatible with the time-of-flight time analyzer.

Time analyzer is the central part of the time-of-flight analysis. It behaves like a multi-channel analyzer in time domain, where varying time differences constitute the time span of the spectrum. In order to do that, the time difference between the two signals is discretized. If the time analyzer reads a signal that falls into a discrete time channel, it increases the counter value associated with this particular channel by one. This way, a spectral distribution is created where the left-hand side of the spectrum represents the smallest time difference and hence the fastest traveling recoils.

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PREPARING THE TEST SAMPLE FOR INITIAL EXPERIMENTATION

Time-of-flight test system will ultimately be used in front of the reactor beam for industrial test samples, particularly from the semiconductor industry. However, preliminary experimentation with the system and at the earlier stages will require an adaptation process. In order to avoid unnecessary occupation of the nuclear reactor time, we decided to proceed with a test sample that will give a detectable depth profile to test the integrity and reliability of the setup. Once we become confident that the depth profile obtained by the time-of-flight setup is within the limits of expectations, we then plan to start to repeat the NDP experiments that were done with conventional methods.

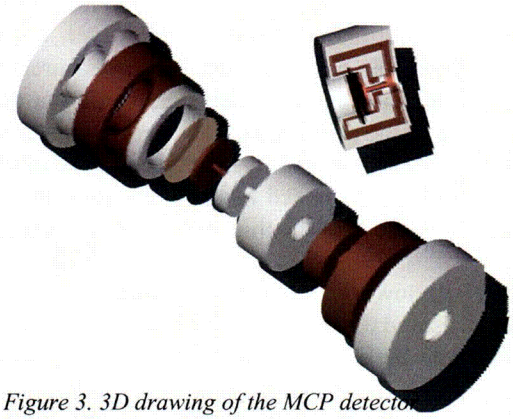

Figure 3. 3D drawing of the MCP detector holder. The assembly was designed and manufactured at the Breazeale Nuclear Reactor machine shop.

The test sample will be a monoenergetic alpha source. Polonium-210 is an isotope that emits alpha particles single energy and not followed by any additional radiation. This alleviates the analysis of signals by the electronic circuitry.

In order to get a depth distribution that will emphasize the functionality of the system, we decided to do a polonium-210 surface implantation on a thin silver foil. The electrochemistry between silver and polonium makes it possible to do surface implantation without employing sophisticated techniques. The affinity of silver to polonium forces polonium atoms to diffuse into a certain depth from the surface, but not get distributed homogeneously. This is done by putting the silver foil into an acidic polonium solution, in this case polonium-210. Because of the surface affinity in silver, polonium spontaneously deposits itself on the surface of the foil creating an alpha emitter depth profile.

SETTING UP THE TOF NDP SYSTEM

Time-of-flight NDP system includes two multi-channel plate detectors (MCP), a vacuum chamber, vacuum pumps, and signal processing electronics.

Multi-channel plate (MCP) detectors are very sensitive devices that can easily become defective. We have MCP detectors that are high-precision that were purchased from Hamamatsu. However, we decided to use MCP's that have manufacturing fault but are still functional in order to avoid the expense of renewing the equipment. The detectors are provided to us by a professional affiliate of the project. However, the MCP's that are given to us were bare MCP detectors without the assembly. We designed a modular assembly that can operate with various dimensions of MCP detectors and for high voltage levels. Figure 3 shows the 3D CAD drawing of the design.

We also upgraded the PC interface of the time analyzer from an ISA-compatible card to a PCI-compatible card. This gave us the flexibility of using more up-to-date computers and operating systems.

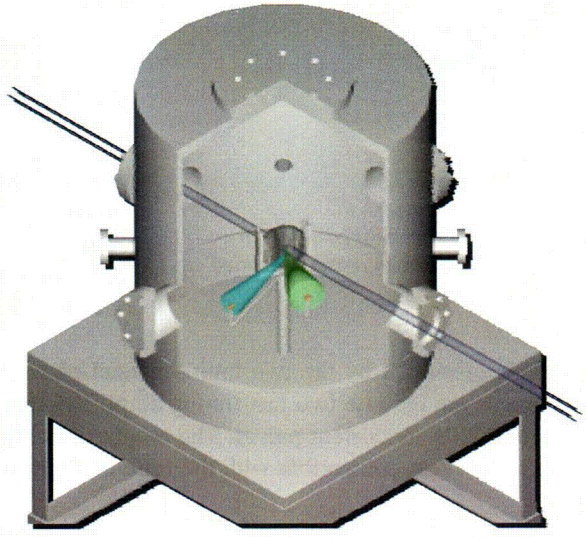

Figure 4. 3D CAD drawing of the vacuum chamber with the sample and two MCP detectors. Neutron beam shines onto the sample containing boron-10 and depth profiling is obtained by analyzing the back emission spectrum.

Figure 4 shows a 3D CAD drawing of the vacuum chamber, two MCP detectors and the neutron beam. The drawing is a downscaled representation of the actual vacuum chamber.

The neutron beam enters the chamber through one of the thin aluminum windows and shine on the sample. The neutrons in the beam interact with boron-10 atoms and create alpha and lithium particles. The charged particles are emitted isotropically with respect to the original location of the isotope. From the back emission of recoils and electrons that are ejected from the surface along with recoils, we get the time-of-flight spectra of particles, as explained in more detail in the foregoing section.

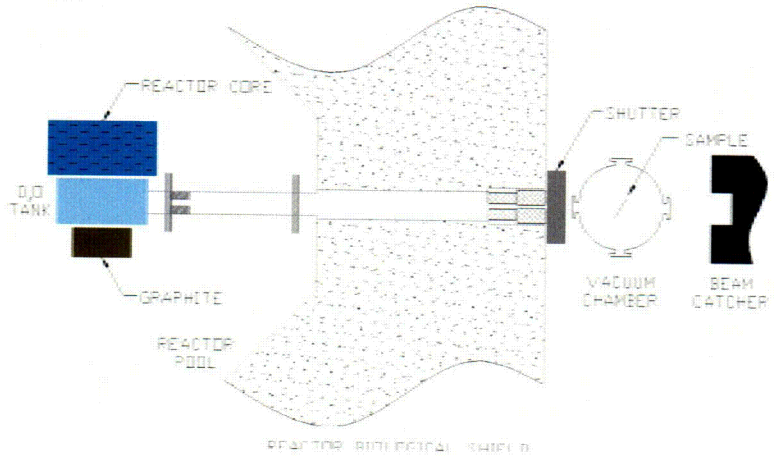

Figure 5. Simplified schematics of the vacuum chamber, beam tube and the reactor

The layout of the test setup in the reactor beam lab is shown in Figure 5. The vacuum chamber is placed in front of one of the beam tubes and is aligned with the neutron beam so that the beam crosses the sample as shown in Figure 4. During the experiment, the reactor core is placed by the D_2O tank. When the reactor reaches the requested power level, the shutter is opened allowing the neutron beam to enter the chamber.

CONCLUSION AND FUTURE WORK

As the technology progresses the size of the semiconductor devices go down significantly. The nominal device thickness until couple of generations ago was around 200 nm. Conventional TOF technique provided ample resolution for decent analysis. However, especially with the arrival of ultra-shallow junctions, the technology is now going towards device thicknesses below 90 nm. The resolution obtained by conventional NDP (~ 15-20 nm) is obviously not a statistically adequate represen-tative of such figures. We anticipate a much higher resolution from TOF NDP, less than 5 nm, and this will make it possible to detect isotope profiles of thicknesses less than 100 nm.

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ACKNOWLEDGEMENT

This project is sponsored by U.S. Department of Energy under Nuclear Engineering Education Research (NEER) grant DE-FG07-00ID-13921.

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AUTOMATED THREE-DIMENSIONAL MONTE CARLO BASED DEPLETION METHODOLOGY FOR PSBR CORE

Participants: K. Ivanov, Professor

C. Tippayakul, Graduate Student

The research is focused on the application of the Monte Carlo techniques to the PSBR core calculation. The Monte Carlo code, MCNP5, is being employed to analyze the PSBR core. In addition, the ORIGEN2.2 code has been coupled with the MCNP5 code in order to introduce the depletion calculation capability to the PSBR core analysis code system. The interfacing between the two codes is performed by a new developed code, TRIGSIM. The TRIGSIM code provides a convenient PSBR core analysis tool to the users since it automatically generates both MCNP input and ORIGEN input from a simpler TRIGSIM input. The MCNP input for PSBR core is generated based on the geometry and the fuel composition of each fuel element provided by the TRIGSIM input. Subsequently, the TRIGSIM code calls the MCNP code to execute the calculation and extracts the MCNP output to generate ORIGEN input. Finally, the TRIGSIM code calls the ORIGEN code to execute the calculation and extracts the ORIGEN output to generate MCNP input for the new burnup step. The current PSBR core loading 51 is being analyzed by the TRIGSIM code. The initial fuel composition of each fuel element is determined by utilizing the HELIOS-1.7 code to perform the burnup calculation up to the current burnup of each fuel element.

New developments will be utilized in the TRIGSIM code system in the future. These include the development of Monte Carlo acceleration scheme for PSBR core, the generation of burnup cross section library for TRIGA fuel types and the development of the coupled Monte Carlo/Nodal methodology to efficiently provide better spatial distributions of the PSBR core. Furthermore, the TRIGSIM code system will be employed to analyze the new PSBR core loading 52.

Master's Thesis:

C. Tippayakul, K. N. Ivanov, C. F. Sears, G. M. Morlang and B. J. Heidrich, "Automated Three-dimensional Depletion Capability for the Pennsylvania State University Research Reactor", Proceedings of PHYSOR2004, April 25-29, 2004, Chicago, IL, USA.

AUTOMATED THREE-DIMENSIONAL MONTE CARLO BASED DEPLETION METHODOLOGY FOR PSBR CORE

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Master's Thesis:

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PARALLEL TRANSPORT MODEL BASED ON 3-D CROSS-SECTION GENERATION FOR TRIGA CORE ANALYSIS

Participants: K. Ivanov, Professor

N. Kriangchaiporn, Graduate Student
C. Tippayakul, Graduate Student

The purpose of this project is to develop reactor core physics model based on 3-D parallel transport methodology utilizing 3-D multigroup fuel lattice cross-section generation and core calculation. The resulting accurate and efficient calculation scheme is intended to be flexible in its application by using adaptive algorithms. The focus of the research is a new methodology for enhanced core physics simulation of the PSBR.

The new 3-D parallel transport calculation scheme for reactor core simulations is based on the PENTRAN code. The complete methodology includes development of algorithms for 3-D cross-section generation and modeling. This will solve several major weaknesses of the current reactor core analysis methodology (the diffusion approximation of the whole core calculations), the shortcomings of generation of multigroup cross section, and the approximations introduced with cross-section parameterization and functionalization.

At present, the fine- and broad- group structures for the TRIGA cross-section generation problems were developed based on the CPXSD (Contribution and Point-wise Cross-Section Driven) methodology in a 2-D fuel cell model. The parametric studies for S_N calculations were performed to evaluate the impact of the spatial meshing, angular, and scattering order variables and to obtain the suitable values for cross-section collapsing and homogenization of the TRIGA cell problem. The DORT calculation shows that the meshing with 6132-mesh model, S10 quadrature order of Legendre-Chebychev technique, and P1 scattering order are the appropriate model for our calculations. Utilizing the scalar flux weighting technique, the 18-broad group structure (18G) was collapsing from 279G with the CPXSD methodology. It was demonstrated that the broad-group library is in close agreement with its fine-group library, within 0.01% Δk/k. Also, comparing with the continuous energy Monte Carlo predictions, we have demonstrated that these new libraries yield good results, with deviations less than 0.08% Δk/k. In addition to cross-section group condensation, we also perform the cross-section homogenization. Compared to broad-group heterogeneous cross sections, the broad-group-homogeneous cross-sections results differed by ~0.2% Δk/k.

Ph.D. Thesis:

N. Kriangchaiporn, K. Ivanov, A. Haghighat, and C.F. Sears (2003). "Parallel Transport Model based on 3-D Cross-Section Generation for TRIGA Core Analysis." *A Docotal Thesis Proposal.* In progress.

Publications:

N. Kriangchaiporn, K. Ivanov, C. Sears, G. Morlang, and B. Heidrich. (2001). Advanced Fuel Management Code System for the Pennsylvania State University Breazeale Reactor (PSBR). TANSAO. 85:415-417.

N. Kriangchaiporn, K. Ivanov, A. Haghighat, and C. Sears. (2004). Multi-Group Cross-Section Generation for TRIGA Core Analysis. TANSAO.

MODELING OF EXISTING BEAM-PORT FACILITY AT PENN STATE UNIVERSITY BREAZEALE REACTOR BY USING MCNP

Participants: K. Ivanov, Professor
Y. Azmy, Professor
J. Brenizer, Nuclear Engineering Department Chair and Professor
K. Ünlü, Professor

F. Alim, Graduate Student
B. Sarikaya, Graduate Student

Services Provided: Neutron Beam Laboratory

Sponsor: DOE, Innovations in Nuclear Infrastructure and Education (INIE)

INTRODUCTION

The Penn State University (PSU) Code System that has been developed to perform computer simulations of the beam port facility at the Reactor Science and Engineering (RSEC) at PSU consists of two major parts, the core model and the beam port model. The core model is needed to compute the flux at the reactor core – beam port facility boundary so that it can be used to compute the flux at the end of beam port where the experimental data were taken. Core calculations are performed by using the nodal diffusion code ADMARC-H[1]. The few-group cross section library needed to perform the diffusion calculations with ADMARC-H has been generated by the lattice physics code HELIOS [2]. The beam port calculations require very detailed geometrical definition of the system. This complexity of the geometrical model and the number of materials used in modeling the beam port facility prevent the use of deterministic codes in this study. Therefore, because of its geometrical flexibility a general Monte Carlo N-Particle Transport Code, MCNP5 [3], is used in this study to model the beam port facility. The source distribution used in beam port model is taken from the ADMARC-H code. An interface program has been developed at PSU to link the diffusion code to the neutron transport code. This interface reads the ADMARC-H output then computes the source term for MCNP and finally prepares the necessary MCNP input card in the requested format. The core model, the interface module, and the beam port model were described in RSEC 2003 annual report. Verifications of these models and applications of the tools developed for these models will be described in this report.

VERIFICATION AND APPLICATION OF THE PSU CODE SYSTEM

Verification

The results of the overall PSU Code Package, which contains the core model, the beam port model that consists of the D_2O tank and the beam port tube models, and the interface module to link these two models are verified by comparing these results with the available experimental data [4] as shown in Figure 1.

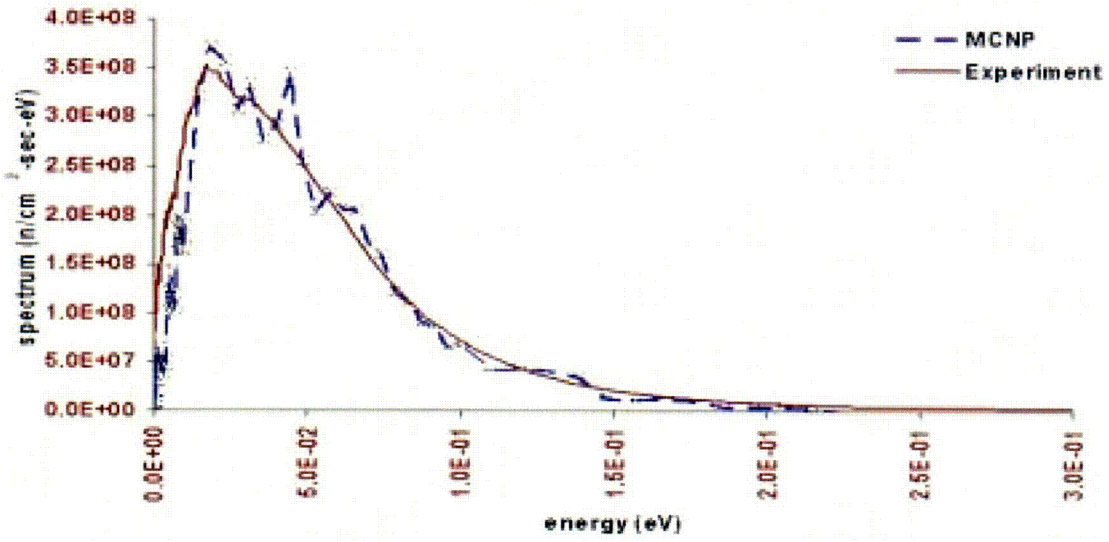

Figure 1: Comparison of the results of the PSU Code Package with the experimental data for the exit of the beam port #4. The solid curve represents the experimental data and the dashed line represents the model predictions with the associated error bars (the dotted vertical lines).

Applications

After establishing the tools for the beam port design study, these tools were used to model beam port #7. Two different MCNP generated plots of the model are given in Figures 2.a and 2.b since beam port #4 and #7 are axially located at different elevations.

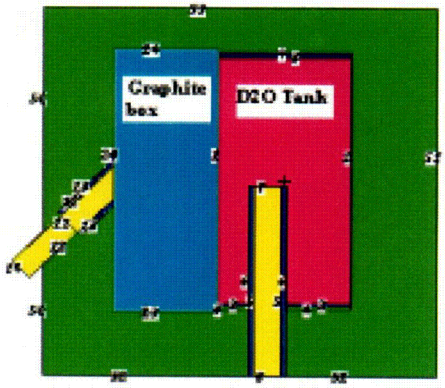

Figure 2.a: BP#7 @ pz=7.0 cm plane

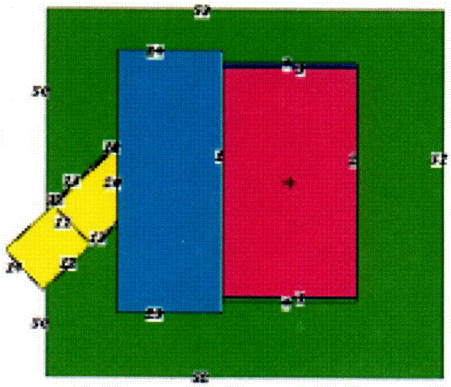

Figure 2.b: BP #7 @ pz=12.7 cm plane

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Both figures show the top view of the system at different axial locations. Since both beam ports and the D_2O tank are cylindrical in shape, in both plots, their sizes differ at different elevations. The same methodology used in the BP #4 calculations was applied for the BP #7 calculations. The results of the D_2O tank model for $9x10^8$ neutron histories with the associated statistical errors are shown in Figure 3.

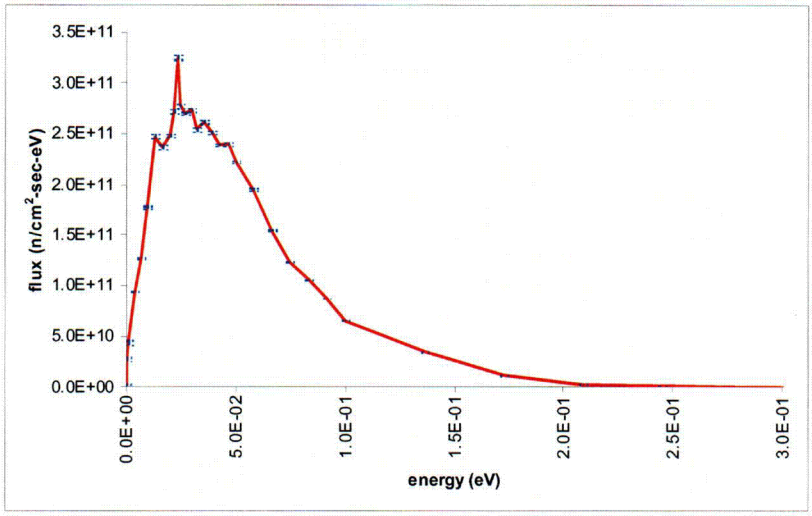

Figure 3: The D_2O tank results for BP #7 (all angles). The solid line represents the model predictions and the dotted lines represent the associated error bars (statistical error in the calculations)

This result represents the spectrum at the tallied surface for all angles. However, in order to prepare the input for the beam guide tube, a highly collimated neutron flux was needed. Therefore, the D_2O tank model was designed to tally for this very highly collimated flux, and this study is still underway and has been running.

Even though the verification of the system was made for the neutron analysis, we turned on the gamma analysis option in the MCNP calculations and performed an analysis for the neutron induced gammas within the system (not core gammas). Figure 4 shows the plot of the gamma spectrum at the beginning of the beam port guide tube (end of D_2O tank model) for all angles.

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CONCLUSIONS AND FUTURE WORK

In this study, the existing beam port facilities at PSU Breazeale Reactor were modeled by using a code package developed at PSU, which consists of two major steps, the core calculations and the beam port facility calculations. The core calculations were performed by using the diffusion code ADMARC-H, which utilizes a few-group cross section library developed with HELIOS. MCNP5 was used to perform the beam port facility model calculations. The link between the core calculations and the beam port calculations was established with an interface program specifically prepared for this study.

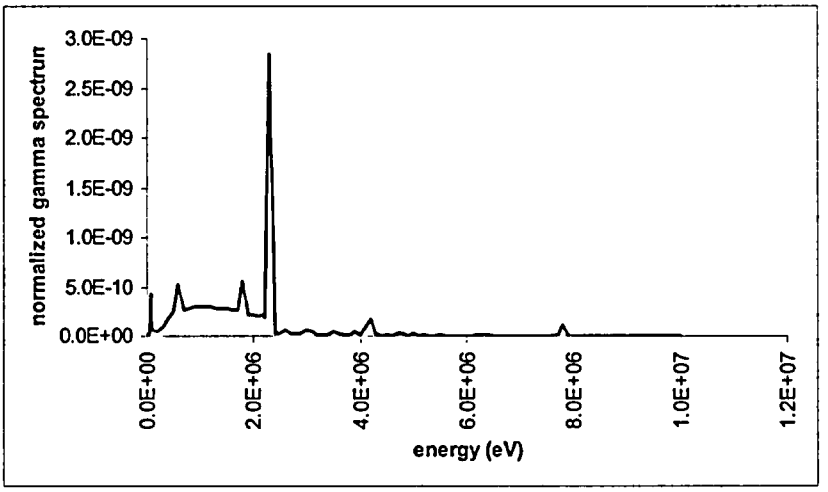

Figure 4: Gamma spectrum at the entrance of the beam port guide tube (BP #4)

The beam port #4 model was used to verify the PSU code package since the experimental data for this beam port and core configuration was available. The results presented for the beam port #4 model showed that the prediction of PSU code system agrees well with the available experimental data [5,6].

The same tools and methodology were used to simulate the beam port #7. Since beam port #7 is located 5" lower than beam port #4, which is exactly located at the axial centerline of the reactor core and since there is more D_2O and an extra graphite block in between the beam port #7 and the reactor core, the number of neutrons that can reach up to the beam port #7 is much less than that of the beam port #4. Therefore, the statistics of the beam port #7 calculations were worse than that of the beam port #4 calculations for the same number of histories. Hence, beam port #7 calculations were performed for much longer histories.

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Anthropology Department

NAA ANALYSIS OF PREHISTORIC METARHYOLITE ARTIFACTS FROM VIRGINIA AND MARYLAND

Participants: K. Hirth, Professor

G. Bondar, Ph.D. Candidate
J. Fleming, Undergraduate

Services Provided: Neutron Irradiation, Radiation Counters, Laboratory Space

The goal of this research is to trace distinctive artifacts manufactured from metarhyolite to known prehistoric quarries in North Carolina, Virginia, Maryland, and Pennsylvania. The artifacts of the Broadspear Horizon form a distinctive and intrusive element from 4,000 to 3,000 years ago in the archaeological record of this region. However, explanations for this cultural discontinuity vary.

This project tests the hypothesis that the prehistoric culture which produced these artifacts spread from south to north through the study area. Results of NAA of 65 artifacts from twenty-one archaeological sites in Virginia, and eight others from Maryland, will be matched to the extensive database of characterized source material from previous research at Penn State's Breazeale Reactor. Preliminary statistical results suggest that a transition point from southern sources (NC and VA) to northern sources (MD and PA) exists in the study transect just north of the Rappahannock watershed in Virginia. While these results generally conform with those from a parallel study of artifact form, and appear to support the hypothesis, the final implications of these results remain to be determined.

Figure 1: Metarhyolite broadspear from Watkins Ilsand, Maryland (44FXH) in the Potomac River.

Figure 2: Metarhyolite broadspear from the Robinson Collection (44MCX32) along the Roanoke River in southern Virginia.

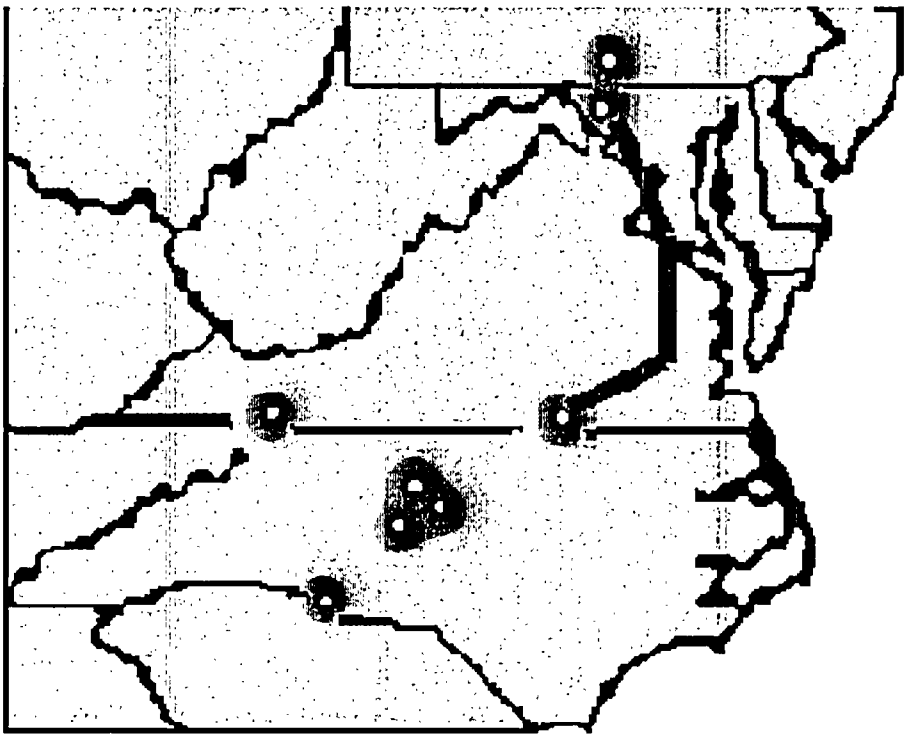

Figure 3: Location of the study transect along the upper limit of the Fall Zone in Virginia and Maryland.

Ph.D. 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.

Biochemistry Department

THE USE OF HIGH-ENERGY GAMMA IRRADIATION TO EFFECT CRYOREDUCATION OF METTALLOENZYMES FOR SPECTROSCOPIC CHARACTERIZATION

Participants: M. Bollinger, Jr., Associate Professor
M. Green, Assistant Professor
R.B. Guyer, Research Technician
C. Krebs, Assistant Professor

J.C. Price, Graduate Student
L. Saleh, Graduate Student
K. Stone, Graduate Student

Services Provided: Gamma Irradiation

Sponsor: Project 1: grant GM 69657 from NIH to CK and JMB ($ 256,000/year).
Project 2: grant GM 55365 from NIH to JMB ($ 157,500 per year).
Project 3: grant GM 47295 to BHH ($190,000/year).
Project 4: grant 39647-G3 from ACS/PRF to MTG ($ 17,500/year).

Enzymes containing metal ions are wide-spread in nature and play a pivotal role in almost every aspect of life; they catalyze numerous biochemical transformations, such as key steps in the biosynthesis of DNA and antibiotics. The main purpose of our research program is to define the mechanisms on a molecular level, by which metallo-enzymes catalyze these reactions. To accomplish this goal, we employ time-resolved spectroscopic methods with the aim to identify and characterize reaction intermediates and thereby deconvoluting the catalytic mechanism.

Significant information about such species can be gained from studies of samples that have been exposed to gamma-irradiation (total dose 2 to 5 Mrad) at low-temperatures (77 K), a.k.a. 'cryoreduction'. It has been demonstrated (Davydov et al. JACS 1994, 116, 11120-11128 and references therein) that this procedure allows reduction of the metal clusters while retaining the geometry of the oxidized cluster, because the molecular motion of the radiolytically reduced metal center is impeded due to the low temperature.
This method is extremely valuable for the study of diamagnetic species, because they can be converted to paramagnetic species, which can then be interrogated in detail by paramagnetic methods, such as EPR, ENDOR, ESEEM, and Mössbauer spectroscopies. We employ this methodology to study the following projects:

1) We have recently used this method for the initial characterization of the first reaction intermediate in a mononuclear non-heme Fe-enzyme. In particular, the assignment that this species contains formally a high-spin Fe(IV) center was made possible by this technique. Additional information about the geometric and electronic structure will be obtained by the other, above-mentioned methods. Status: in progress

2) We have identified several peroxodiferric reaction intermediates in the reactions of non-heme diiron enzymes. Such species are believed to be key species in some of the non-heme diiron enzymes, and in order to gain insight into the reaction mechanisms detailed insight into the geometric and electronic structure is of high importance. We intend to employ the cryoreduction method to study the diamagnetic peroxodiferric species by the above paramagnetic methods. Status: in progress

3) In collaboration with Boi Hanh Huynh, Emory University, we will study the enzyme ferredoxin:thioredoxin reductase, which contains an unusual iron-sulfur cluster. Again, we will attempt to convert the diamagnetic cluster to a paramagnetic cluster by cryoreduction and gain information about this species by the above methods. Status: in progress

4) We use this method to study the geometric and electroninc structure of ferryl-oxo reaction intermediates of P450 heme enzymes. These enzymes play a key role in numerous aspects of biology, and the elucidation of their structure is paramount for the understanding of their function. Status: in progress

Ph.D. Theses:

John C. Price, J. Martin Bollinger, Jr. (advisor), and Carsten Krebs (advisor):
Mechanistic and Structural Studies on Taurine:α-Ketoglutarate Dioxygenase

Lana Saleh, and J. Martin Bollinger, Jr. (advisor):
Oxygen Activation and Electron Transfer in the R2 Subunit of Ribonucleotide Reductase from *Escherichia coli*

Kari Stone, and Michael T. Green (advisor)
"Mechanism of Oxygen Activation by Chloroperoxidase"

Publications:

Price, J. C., Barr, E. W., Tirupati, B., Bollinger, J. M., Jr., and Krebs, C. The First Direct Characterization of a High-Valent Iron Intermediate in the Reaction of an α-Ketoglutarate-Dependent Dioxygenase: A High-Spin Fe(IV) Complex in Taurine/ -Ketoglutarate Dioxygenase (TauD) from *Escherichia coli* Biochemistry, 42, 7497-7508, 2003

J. M. Bollinger, Jr. Characterization of a High-Spin Fe(IV) Intermediate in the Reaction of Taurine/-Ketoglutarate Dioxygenase (TauD)
Invited talk: 11th International Conference of Biological Inorganic Chemistry. Cairns, Australia, July 2003

Price, J. C., Barr, E. W., Tirupati, B., Bollinger, J. M., Jr., and Krebs, C. On the Identity of a Novel Fe(IV) Intermediate in the Catalytic Cycle of Taurine/-Ketoglutarate Dioxygenase (TauD)
Poster presentation by J.C. Price at the 11th International Conference of Biological Inorganic Chemistry, Cairns, Australia, July 2003

Price, J. C., Barr, E. W., Tirupati, B., Bollinger, J. M., Jr., and Krebs, C. Spectroscopic Characterization of a High-Spin Fe(IV) Intermediate in the Reaction of Taurine/-Ketoglutarate Dioxygenase (TauD)
Poster presentation by C. Krebs at the 11th International Conference of Biological Inorganic Chemistry, Cairns, Australia, July 2003

Carsten Krebs Mechanism of Oxygen Activation by Taurine/-Ketoglutarate Dioxygenase (TauD)
Invited talk: 227th Meeting of the American Chemical Society Anaheim, CA, March 2004

Michael T.Green Role of Thiolate ligation in P450 Enzymes.
Invited lecture: 3rd International Conf. on Porphyrins & Phthalocyanins(ICPP) New Orleans, July 2004

Kari Stone, Carsten Krebs, and Michael T. Green Role of Thiolate ligation in P450 Enzymes.
Poster presented by Kari Stone at the 3rd International Conference on Porphyrins and Phthalocyanins (ICPP) New Orleans, July 2004

Carsten Krebs Mechanism of Oxygen Activation by Taurine/-Ketoglutarate Dioxygenase (TauD)
Invited talk: 7th European Conference on Bioinorganic Chemistry Garmisch Partenkirchen, Germany, August 2004

Price, J. C., Barr, E. W., Tirupati, B., Bollinger, J. M., Jr., and Krebs, C. On the Identity of a Novel Fe(IV) Intermediate in the Catalytic Cycle of Taurine/-Ketoglutarate Dioxygenase (TauD)
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Kari Stone, Carsten Krebs, and Michael T. Green Role of Thiolate ligation in P450 Enzymes.
Poster presentation by Kari Stone at the 7th European Conference on Bioinorganic Chemistry Garmisch Partenkirchen, Germany, August 2004

Civil and Environmental Engineering Department

EFFECTS OF Zn(II), Cu(II), Mn(II), Fe(II), NO_3^- or SO_4^{2-} at pH 6.5 AND 8.5 ON TRANSFORMATIONS OF HYDROUS FERRIC OXIDE (HFO) AS EVIDENCED BY MÖSSBAUER SPECTROSCOPY

Participants: G. Catchen, Professor
B.A. Dempsey, Professor
W. Burgos, Associate Professor

J. Jang, Postdoctoral Research Associate/Graduate Student
B. Park, Graduate Student

Services Provided: Angular Correlations Lab, Laboratory Space

Sponsor: Department of Energy, Natural and Accelerated Bioremediation Research Program, $764,870

The objective of the research is to determine the effects of transition metals on transformation of hydrous ferric oxide (HFO) into more thermodynamically stable ferric oxides. Ferric oxides are important environmental adsorbents. In anoxic environments, ferric oxides with Fe(II) are important redox buffers. Transformation of HFO to more stable phases can result in decreased surface area and reduced redox potential.

In some experiments, HFO was precipitated in the presence of Cu(II), Zn(II), Mn(II) and/or Fe(II). In other experiments, Fe(II), NO_3^-, and/or SO_4^{2-} were added to pre-formed HFO. Transmission ^{57}Fe-Mössbauer spectroscopy was used to monitor the phase changes. At pH 6.5 and 65 °C, HFO was transformed into hematite in the presence of Zn(II) or Mn(II). Both metals were significantly adsorbed for these conditions, occupying about 1.2 sorption sites per nm^2 of HFO surface. Transformations were not observed at pH 6.5 in the presence of Cu(II), which was weakly adsorbed (0.06 sites per nm^2). No transformation occurred in the absence of Me(II) transition metals. At pH 6.5 and room temperature, HFO plus Fe(II) transformed into poorly crystalline goethite in the presence of chloride, into goethite and lepidocrocite in the presence sulfate, and into goethite and magnetite in the presence of nitrate. At pH 8.5 and room temperature, HFO that was formed with 0.033 or 0.33 mM Zn(II) and then aged with Fe(II) was transformed into magnetite that was depleted in octahedral Fe, i.e. non-stoichiometric or possibly mixed metal spinel, $(Fe^{3+})^{IV}(Me_xFe^{2+}{}_{1-x}Fe^{3+})^{VI}O_4$. HFO that was aged with Cu(II) and Fe(II) was transformed into goethite and into magnetite that was also depleted in octahedral Fe. The transformations at pH 8.5 were completely inhibited by 3.3 mM Zn(II) and transformations were significantly decreased by 3.3 mM Cu(II). These results have extended observations of the transformation of HFO to neutral pH ranges and to lower concentrations of metals than previously reported.

Ph.D. Thesis:

Je-Hun Jang, "Chemistry of Environmentally Significant Phases of Oxides of Iron," Dept. of Civil and Environmental Engineering, The Pennsylvania State University, 2004.
Research Supervisor: Dr. Brian A. Dempsey

Publications:

Jang, Je-Hun, Brian A. Dempsey, Gary L. Catchen, and William D. Burgos, "Effects of Zn(II), Cu(II), Mn(II), Fe(II), NO_3^-, or SO_4^{2-} at pH 6.5 and 8.5 on Transformations of Hydrous Ferric Oxide (HFO) as Evidenced by Mössbauer Spectroscopy," Colloids and SurfacesA: Physicochem. Eng. Aspects, 221, 55-68 (2003).

Engineering Science and Mechanics Department

STUDY OF THE CHARGE TRAPPING CHARACTERISTICS OF HfO_2/Si

Participants: P. Lenahan, Professor

A. Kang, Graduate Research Assistant

Services Provided: Gamma Irradiation

Sponsor: Semicondutor Research Corporation ,$250,000

Charge trapping is a major hurdle facing the integration of the high dielectric constant hafnium oxide material in complimentary metal-oxide-semiconductor devices. In collaboration with Sharp Labs of America and funded by the Semiconductor Research Corporation, we made magnetic resonance observations of the effects of flooding the dielectric material with charge carriers, i.e. through gamma irradiation. The irradiation generates several defect centers in the HfO_2 films, although the nature of these defects are still under investigation. It has been shown previously[1] that gamma irradiation induces charge trapping in HfO_2 devices, thus, the observed centers are likely linked to the charge trapping.

1. A.Y. Kang, P.M. Lenahan, and J.F. Conley, Jr., "The Radiation Response of the High Dielectric Constant Hafnium Oxide/Silicon System." *IEEE Trans Nucl. Sci.* 49(6), 2636 (Dec. 2002)

Master's Thesis:

A.Y. Kang, Electron Spin Resonance observation of trapping centers in the high κ hafnium oxide system. May 2004 Advisor: Patrick M. Lenahan

Publications:

A.Y. Kang, P.M. Lenahan, J.F. Conley, Jr., and Y. Ono, "Physical structure of trapped electrons in atomic layer deposited hafnium oxide using Hf(NO3)4 precursor." *34th IEEE Semiconductor Interface Specialists Conference*, Dec 4-6, 2003. Washington D.C.

A.Y. Kang, P.M. Lenahan, J.F. Conley, Jr., and Y. Ono, "Reliability Concerns for HfO2/Si Devices: Dielectric Electron Traps." *International Integrated Reliability Workshop*, Oct. 20-23, 2003. Stanford Sierra Camp, Fallen Leaf Lake, CA.

Materials Sciences and Engineering Department

ORTHOPEDIC BIOMATERIALS

Participants: E.A. Vogler, Professor

X. Liu, Ph.D. Studemt

Services Provided: Gamma Irradiation

Ph.D. Thesis:

Xiaomei Liu and Erwin Vogler, advisor. Influence of Growth Environment on Osteoblast Adhesion, proliferation, Morphology and Focal Adhesion Assembly

Publications:

Xiaomei Liu, Jung Yul Lim, Henry J. Donahue, Erwin A. Vogler. Influence of Substratum Surface Hydrophilicity/ Hydrophobicity on Osteoblast Adhesion, Morphology, and Focal Adhesion Assembly. Biomaterials, submitted.

COMPARTMENTALIZED BIOREACTOR FOR BONE CELL CULTURE

Participants: E.A. Vogler, Professor

D. Ravi, Graduate Student
X. Liu, Graduate Student

Services Provided: Gamma Irradiation

COMPARTMENTALIZED BIOREACTOR FOR LONG-TERM CELL CULTURE

An advanced bioreactor permitting extended term culture of animal cells is reported. The bioreactor is based on the principle of simultaneous-cell-growth-and-dialysis that separates a cell growth chamber from a media reservoir by a dialysis membrane, thus compartmentalizing cell growth and cell nutrition functions. As a consequence of compartmentalization, the pericellular environment is unperturbed by continuous perfusion or punctuated re-feeding schedules and "luxury macromolecules" synthesized by cells are retained in a manner that more closely simulates the in vivo condition. Extended periods of unattended cell processing can thus occur during which secretion of various bioproducts and the development of extracellular matrix can be studied.

Long-term culture in a manner that does not disturb the pericellular environment is particularly significant for bone cells, since bone formation and remodeling is a complex cell-and-protein meditated process occurring over the time frame of weeks to months. With the goal of developing osteoinductive biomaterials as a specific application area, phenotypic behavior of a model human osteoblast cell line (hFOB 1.19, ATCC CRL-11372) and mouse calvaria derived osteoblast cell line (MC3T3, ATCC CRL-2593) cultured in the bioreactor was compared to that observed under conventional culture conditions. Attachment and growth of hFOB and MC3T3 cultured in the bioreactor was evaluated using optical microscopy, scanning and transmission electron microscopy (SEM/TEM). Differentiation was evaluated using Alkaline Phosphatase activity (ALP) staining and Von Kossa assay. hFOB cultured in the reactor for 15 days without sub-culturing formed up to 4 cell layers and stained for ALP activity. In sharp contrast, cells cultured for an equivalent period in conventional tissue culture flasks, also without subculture but re-fed every 2 days, exhibited continuous cell shedding, ruffled edges, and failed to form either multilayers or exhibit ALP activity. MC3T3 cultured in the bioreactor for 30 days, formed a tightly packed, dense layer of cells revealing uniform and extensive mineralization with Von Kossa assay. Results suggest that stable culture conditions afforded by the reactor has enhanced utility in the long-term culture of osteoblasts in terms of cell growth, proliferation and mineralized matrix deposition characteristics. The compartmentalized bioreactor thus shows promise as a tool for long-term culture conditions, and specifically for evaluation of bone-cell interactions with orthopedic biomaterials.

Ph.D. Thesis:

Thesis Title: Compartmentalized Bioreactor for long-term cell culture
Graduate Student: Dhurjati Ravi.
Advisor: Prof. Erwin A. Vogler.

Publications:

Ravi, D, Vogler E.A., Compartmentalized Bioreactor for Long-term Cell Culture,
7 th Annual New Jersey Symposium on Biomaterials, New Brunswick, NJ.

Ravi, D, Vogler E.A., Compartmentalized Bioreactor for Long-term Cell Culture,
Biointerface, Annual Meeting of the Surfaces in Biomaterials Foundation, Baltimore, MD.

Plant Pathology Department, Fusarium Research Center

Participants: J.Juba, Research Support Technologist

Services Provided: Gamma Irradiation

Carnation leaves are irradiated in the Cobalt-60 facility in order to provide a sterile growing medium for Fusarium species at the Fusarium Research facility. Nearly every project in our lab relies on the use of these leaves and as far as I know we are the only source of irradiated carnation leaves worldwide. We make them available to others in the Fusarium research community, charging fees to cover our costs. You might find some helpful information at http://frc.cas.psu.edu/.

Publications:

1. Garzón, C.D., Geiser, D.M., and Moorman, G.W. *Accepted with revision.* Analysis of AFLP and ITS sequence variation reveals a cryptic species boundary within *Pythium irregulare. Phytopathology.*

2. O'Donnell, K., Sutton, D.A., Rinaldi, M.G., Magnon, K.C., Cox, P.A., Revankar, S.G., Sanche, S., Geiser, D.M., Juba, J.H., van Burik, J.H., Padhye, A. and Robinson, J.S. *In Press.* Genetic Diversity of Human Pathogenic Members of the *Fusarium oxysporum* Complex Inferred from Gene Genealogies and AFLP Analyses: Evidence for the Recent Dispersion of a Geographically Widespread Clonal Lineage and Nosocomial Origin. *J. Clin. Microbiol.*

3. Garzón, C.D., Geiser, D.M., and Moorman, G.W. *In Press.* Diagnosis and population analysis of *Pythium* species using AFLP fingerprinting. *Plant Disease.*

4. Geiser, D.M., Lewis Ivey, M.L., Hakiza, G., Juba, J.H. and Miller, S.A. *In Press. Gibberella xylarioides* (anamorph: *Fusarium xylarioides)*, a causative agent of coffee wilt disease in Africa, is a previously unrecognized member of the *G. fujikuroi* species complex. *Mycologia.*

5. Geiser, D.M., Jiménez-Gasco, M., Kang, S., Makalowska, I., Veerarahavan, N., Ward, T.J. Zhang, N., Kuldau, G.A., and O'Donnell, K. 2004. FUSARIUM-ID v.1.0: A DNA sequence database for identifying *Fusarium. European Journal of Plant Pathology* 110: 473-479.

6. O'Donnell, K., Ward, T.J., Geiser, D.M., Kistler, H.C., and Aoki, T. 2004. Genealogical concordance between the mating type locus and seven other nuclear genes supports formal recognition of nine phylogenetically distinct species within the *Fusarium graminearum* clade. *Fungal Genetics and Biology* 41:600-623.

7. Taylor, J.W., Blackwell, M., Geiser, D.M., Hibbett, D.S., James, T.Y., Lutzoni, F., O'Donnell, K.L., Porter, D., Spatafora, J.W., and Spiegel, F. 2004. The History of Fungi. *In:* Assembling the Tree of Life, Cracraft, J. and Donoghue, M.J., eds., Oxford University Press.

8. Geiser, D.M. 2004. Practical fungal molecular taxonomy: *In:* Advances in Fungal Biotechnology for Industry, Medicine and Agriculture. Tkacz, J. and Lange, L., eds. Kluwer Academic Publishers.

9. Geml, J. Geiser, D.M., and Royse, D.J. 2004. Phylogenetic relationships of the genus *Agaricus* . *Mycological Progress* 3: 157-176.

10. Jurjevic, Z., Wilson, D.M., Wilson, J.P., Geiser, D.M., Juba, J.H., Mubatenhema, W., Rains, G.C. and Widstrom, N. *In Press. Fusarium* species and fumonisin production on pearl millet and corn from Georgia, USA. *Mycopathologia.*

Seifert KA, Aoki T, Baayen RP, Brayford D, Burgess LW, Chulze S, Gams W, Geiser, D.M. , de Gruyter J, Leslie JF, Logrieco A, Marasas WFO, Nirenberg HI, O'Donnell K, Rheeder J, Samuels GJ, Summerell BA,

Northeast Technology Corporation

TESTING OF BORAL UNDER CONDITIONS SIMULATING WETTING AND VACUUM DRYING IN SPENT NUCLEAR FUEL STORAGE CASKS

Participants: K. Lindquist, Ph.D.
D. Vonada

Services Provided: Laboratory Space

Sponsor: Electric Power Research Institute, AAR Cargo Systems, Inc., ENRESA

BORAL has been observed to develop large blisters in the aluminum cladding during vacuum drying. Equipment was constructed (Figure 1) to simulate the period when fuel is loaded and the multiple purpose canister (MPC) is in the pool and the BORAL is exposed to the pool water. Following exposure to the pool water the samples of BORAL are placed in a vacuum oven (Figure 2) and slowly brought to 550°F at a controlled rate. This simulates draining of the MPC and vacuum drying.

These studies evaluated BORAL processing variables, MPC drying conditions and as-fabricated BORAL attributes, which have an influence on the propensity for blister formation. The results of the work are providing the manufacturer of BORAL (AAR Cargo Systems, Inc.) with the basis for modifying process variables to provide a blister resistant material.

Figure 1: Aluminum Pressure Vessels and Temperature Controller

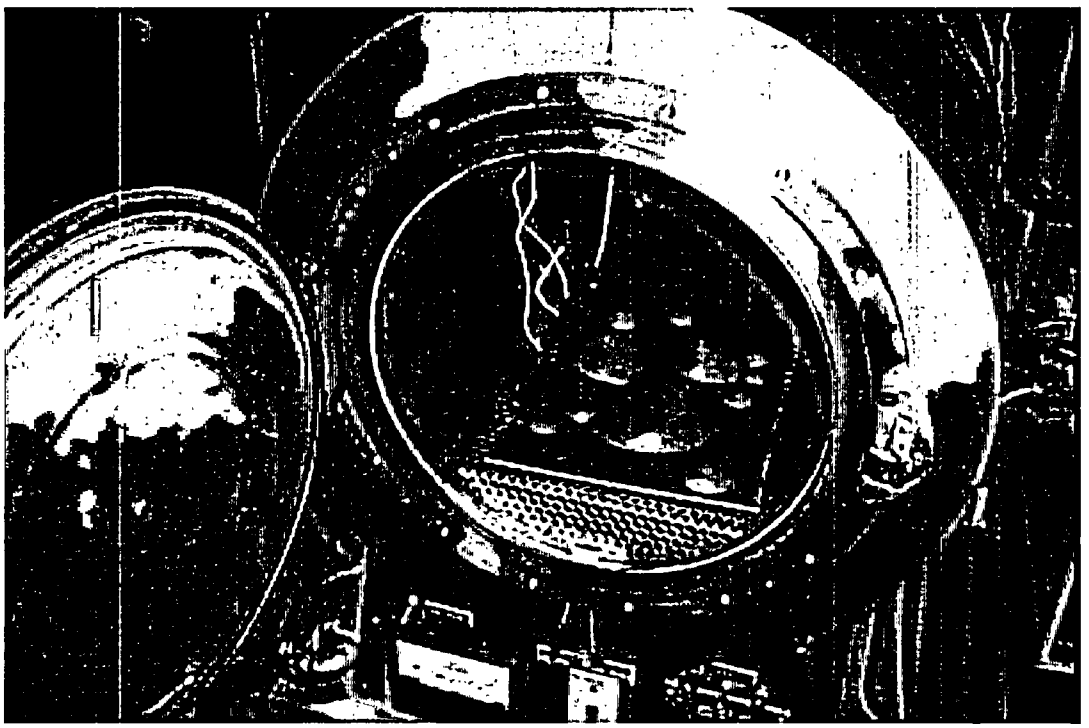


Figure 2: Vacuum Oven

Publications:

EPRI Report 1008441" BORAL Behavior under Simulated Cask Vacuum Drying Conditions", September 2003.

PHYSICAL CHARACTERIZATION OF NEUTRON ABSORBER MATERIALS

Participants: K. Lindquist, Ph.D.
D. Vonada
S. Leuenroth

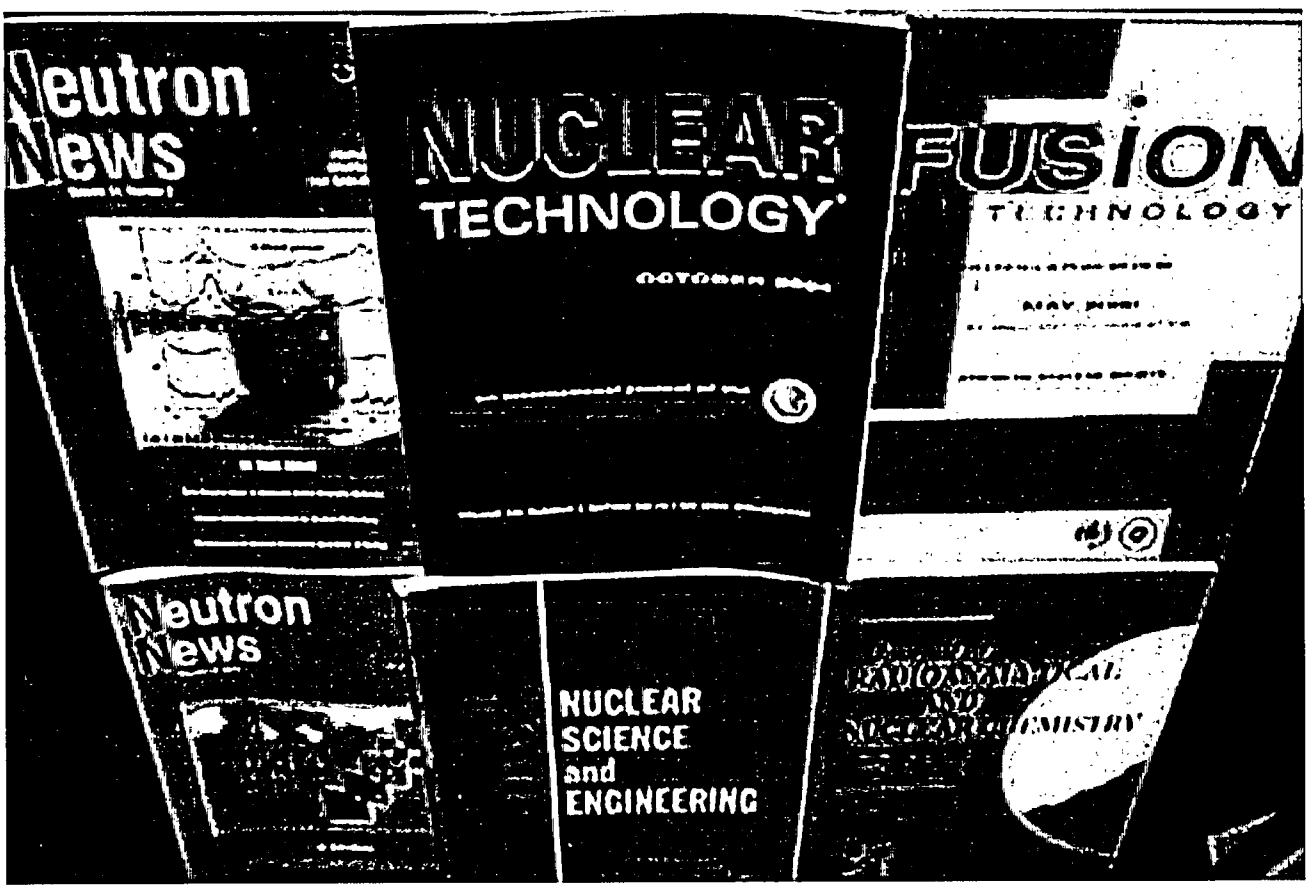
Services Provided: Neutron Irradiation, Laboratory Space

Surveillance coupons from spent fuel pools at nuclear stations are tested and characterized with respect to their physical attributes. Materials tested include BORAL, Boraflex and borated stainless steel. A key attribute tested is the neutron absorption characteristics. This test is performed in the Neutron Beam Laboratory.

SECTION B. OTHER UNIVERSITIES, ORGANIZATIONS & COMPANIES UTILIZING THE FACILITIES OF THE RSEC

University or Industry	Type of Use
ADP Life Sciences	Gamma Irradiation
Clarion University	Neutron Activation Analysis
COGEMA	Neutron Radiography Neutron Radioscopy Neutron Transmission
Cornell University	Neutron Radioscopy
David Martin	Gamma Irradiation
Eagle-Picher	Neutron Radiography Neutron Radioscopy Neutron Transmission
Exelon	Neutron Transmission
Fairchild Corporation, Mountaintop	Semiconductor Irradiation
Fairchild Corporation, South Korea	Semiconductor Irradiation
General Motors	Neutron Radiography Neutron Radioscopy
Lockheed Martin	Semiconductor Irradiation
NETCO (Northeast Technology Corporation)	Neutron Radioscopy Neutron Transmission
Northrup-Grumman (formerly TRW)	Irradiation of Electronic Devices
Novax, Inc.	Neutron Irradiation
NWT	Isotope Production
Physical Acoustics	Neutron Irradiation Gamma Irradiation
Primasep	Gamma Irradiation
Raytheon Company, Sudbury, MA	Irradiation of Electronic Devices
Raytheon Systems Company, El Sequndo, CA	Irradiation of Electronic Devices
Raytheon, St. Petersburg, FL	Irradiation of Electronic Devices
Richard Gazzini	Gamma Irradiation
SAIC	Neutron Irradiation
Suntronics	Neutron Irradiation
Syngenta Crop Production	Gamma Irradiation
Toyota	Neutron Radioscopy
TRACERCO (formerly Synetix, Inc.)	Isotope Production
Tru-Tec	Isotope Production
University of Pittsburgh, Greensburg	Neutron Activation Analysis
Westinghouse Science & Technology Center	Neutron Irradiation

PUBLICATIONS



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B. Sarikaya, F. Alim, K. Ivanov, K. Ünlü, J. Brenizer, Y. Azmy, "*Modelling of Existing Beamport Facility at PSU Breazeale Reactor by using MCNP*", Proceedings of PHYSOR 2004 -The Physics of Fuel Cycles and Advanced Nuclear Systems: Global Developments Chicago, Illinois, April 25-29, (2004)

C. Tippayakul, K. N. Ivanov, C. F. Sears, G. M. Morlang and B. J. Heidrich, "Automated Three-dimensional Depletion Capability for the Pennsylvania State University Research Reactor", Proceedings of PHYSOR2004, April 25-29, 2004, Chicago, IL, USA.

D.K. Hauck, K. Ünlü, P.I. Kuniholm, J.J. Chiment, "*Uses of NAA: Gold Concentrations in Dated Tree Rings,*" Trans. Am. Nucl. Soc., 90, 320 (2004).

J. Brenizer, C. F. Sears, K. Ünlü, L. H. Tsoukalas, T. Jevremovic, J. Stubbins, R. Agasie, M. Corradini, "*An Update of the Consortium of Big-10 University Research and Training Reactors INIE Activities*", Trans. Am. Nucl. Soc., 88, 649 (2003).

J. Brenizer, C. F. Sears, K. Ünlü, L. H. Tsoukalas, T. Jevremovic, J. Stubbins, R. Agasie, M. Corradini, " *A Review of Year One INIE Activities of the Consortium of BIG-10 URTR's*", Trans. Am. Nucl. Soc., 89, 858 (2003).

J. Niederhaus, J. Brenizer, K. Ünlü, "*Development of a Single-Disk Neutron Chopper for Time-of Flight Spectrometry at Penn State*", Trans. Am. Nucl. Soc., 89, 677 (2003).

J. Niederhaus, J. Brenizer, K. Ünlü, "*Thermal Neutron Time-of-Flight Spectroscopy at Penn State using a Single-Disk Chopper*", Proceedings of PHYSOR 2004 -The Physics of Fuel Cycles and Advanced Nuclear Systems: Global Developments Chicago, Illinois, April 25-29, (2004)

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N. Kriangchaiporn, K. Ivanov, A. Haghighat, and C. Sears. (2004). Multi-Group Cross-Section Generation for TRIGA Core Analysis. TANSAO.

N. Kriangchaiporn, K. Ivanov, C. Sears, G. Morlang, and B. Heidrich. (2001). Advanced Fuel Management Code System for the Pennsylvania State University Breazeale Reactor (PSBR). TANSAO. 85:415-417.

N. Pekula , K. Heller, P. A. Chuang, A. Turhan, M.M. Mench, J. S. Brenizer, K. Ünlü, " Study of Water Distribution and Transport in a Polymer Electrolyte Fuel Cell Using Neutron Imaging," Nuclear Instrumentation Methods, Section A. (Accepted for publication)

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Plant Pathology Department

C.D. Garzón, Geiser, D.M., and Moorman, G.W. *Accepted with revision.* Analysis of AFLP and ITS sequence variation reveals a cryptic species boundary within *Pythium irregulare. Phytopathology.*

K. O'Donnell, Sutton, D.A., Rinaldi, M.G., Magnon, K.C., Cox, P.A., Revankar, S.G., Sanche, S., Geiser, D.M., Juba, J.H., van Burik, J.H., Padhye, A. and Robinson, J.S. *In Press.* Genetic Diversity of Human Pathogenic Members of the *Fusarium oxysporum* Complex Inferred from Gene Genealogies and AFLP Analyses: Evidence for the Recent Dispersion of a Geographically Widespread Clonal Lineage and Nosocomial Origin. *J. Clin. Microbiol.*

C.D.Garzón, Geiser, D.M., and Moorman, G.W. *In Press.* Diagnosis and population analysis of *Pythium* species using AFLP fingerprinting. *Plant Disease.*

D.M. Geiser, Lewis Ivey, M.L., Hakiza, G., Juba, J.H. and Miller, S.A. *In Press. Gibberella xylarioides* (anamorph: *Fusarium xylarioides)*, a causative agent of coffee wilt disease in Africa, is a previously unrecognized member of the *G fujikuroi* species complex. *Mycologia.*

D.M. Geiser, Jiménez-Gasco, M., Kang, S., Makalowska, I., Veerarahavan, N., Ward, T.J. Zhang, N., Kuldau, G.A., and O'Donnell, K. 2004. FUSARIUM-ID v.1.0: A DNA sequence database for identifying *Fusarium. European Journal of Plant Pathology* 110: 473-479.

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J.W. Taylor, Blackwell, M., Geiser, D.M., Hibbett, D.S., James, T.Y., Lutzoni, F., O'Donnell, K.L., Porter, D., Spatafora, J.W., and Spiegel, F. 2004. The History of Fungi. *In:* Assembling the Tree of Life, Cracraft, J. and Donoghue, M.J., eds., Oxford University Press.

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J. Geml, Geiser, D.M., and Royse, D.J. 2004. Phylogenetic relationships of the genus *Agaricus* . *Mycological Progress* 3: 157-176.

Z. Jurjevic, Wilson, D.M., Wilson, J.P., Geiser, D.M., Juba, J.H., Mubatenhema, W., Rains, G.C. and Widstrom, N. *In Press. Fusarium* species and fumonisin production on pearl millet and corn from Georgia, USA. *Mycopathologia.*

K.A. Seifert, Aoki T, Baayen RP, Brayford D, Burgess LW, Chulze S, Gams W, Geiser, D.M. , de Gruyter J, Leslie JF, Logrieco A, Marasas WFO, Nirenberg HI, O'Donnell K, Rheeder J, Samuels GJ, Summerell BA,

Northeast Technology Corporation

EPRI Report 1008441" BORAL Behavior under Simulated Cask Vacuum Drying Conditions", September 2003.

Biochemistry Department

J.C. Price, Barr, E. W., Tirupati, B., Bollinger, J. M., Jr., and Krebs, C. The First Direct Characterization of a High-Valent Iron Intermediate in the Reaction of an α-Ketoglutarate-Dependent Dioxygenase: A High-Spin Fe(IV) Complex in Taurine/-Ketoglutarate Dioxygenase (TauD) from *Escherichia coli* Biochemistry, 42, 7497-7508, 2003

Civil and Environmental Engineering Department

J. Jang, Brian A. Dempsey, Gary L. Catchen, and William D. Burgos, "Effects of Zn(II), Cu(II), Mn(II), Fe(II), NO_3^-, or SO_4^{2-} at pH 6.5 and 8.5 on Transformations of Hydrous Ferric Oxide (HFO) as Evidenced by Mössbauer Spectroscopy," Colloids and SurfacesA: Physicochem. Eng. Aspects, 221, 55-68 (2003).

Engineering Science and Mechanics Department

A.Y. Kang, P.M. Lenahan, J.F. Conley, Jr., and Y. Ono, "Physical structure of trapped electrons in atomic layer deposited hafnium oxide using Hf(NO3)4 precursor." *34th IEEE Semiconductor Interface Specialists Conference*, Dec 4-6, 2003. Washington D.C.

A.Y. Kang, P.M. Lenahan, J.F. Conley, Jr., and Y. Ono, "Reliability Concerns for HfO2/Si Devices: Dielectric Electron Traps." *International Integrated Reliability Workshop*, Oct. 20-23, 2003. Stanford Sierra Camp, Fallen Leaf Lake, CA.

D. Ravi, Vogler E.A., "Compartmentalized Bioreactor for Long-term Cell Culture." *7 th Annual New Jersey Symposium on Biomaterials*, New Brunswick, NJ.

D. Ravi, Vogler E.A. "Compartmentalized Bioreactor for Long-term Cell Culture." *Biointerface, Annual Meeting of the Surfaces in Biomaterials Foundation*, Baltimore, MD.

Ph.D. THESES

Biochemistry Department

J. C. Price, J. Martin Bollinger, Jr. (advisor), and Carsten Krebs (advisor). Mechanistic and Structural Studies on Taurine:?-Ketoglutarate Dioxygenase

L. Saleh, and J. Martin Bollinger, Jr. (advisor). Oxygen Activation and Electron Transfer in the R2 Subunit of Ribonucleotide Reductase from *Escherichia coli*

K. Stone, and Michael T. Green (advisor). "Mechanism of Oxygen Activation by Chloroperoxidase"

Civil and Environmental Engineering Department

J. Jang, "Chemistry of environmentally significant phases of oxides of iron," Dept. of Civil and Environmental Engineering, The Pennsylvania State University, 2004.
Research Supervisor: Dr. Brian A. Dempsey

Engineering Science and Mechanics Department

X. Liu, Erwin Vogler, advisor. Influence of Growth Environment on Osteoblast Adhesion, proliferation, Morphology and Focal Adhesion Assembly

D. Ravi, E.A. Vogler. "Compartmentalized Bioreactor for long-term cell culture."

MASTER'S THESES

Mechanical and Nuclear Engineering Department

C. Tyree. "*Neutron Irradiated Silicon Carbide Studied Using Positron Annihilation Lifetime Spectroscopy,*" Advisors: G. Catchen, A. Motta. (2004).

N. Pekula, "Visualization and Measurement of Water Accumulation and Transport in an Operating PEFC Using Neutron Imaging", M. S. Thesis, Spring 2004.

N. Kriangchaiporn, K. Ivanov, advisor. Advanced Fuel Management System (AFMS) for PSBR, 2001.

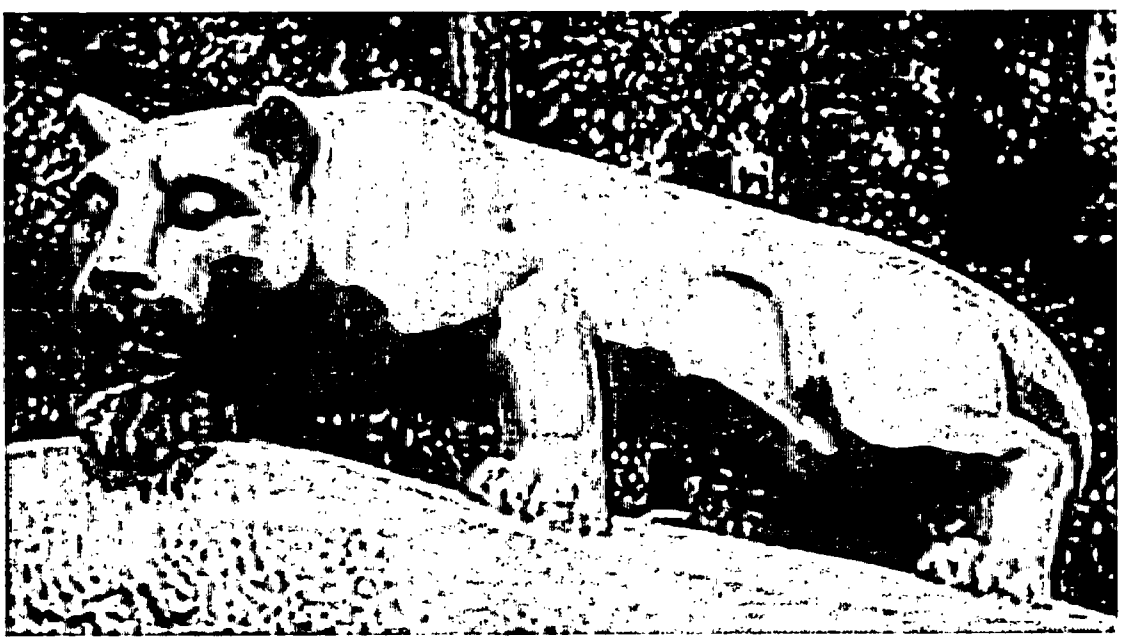
N. Kriangchaiporn, K. Ivanov,A. Haghighat, C.F. Sears (2003). "Parallel Transport Model based on 3-D Cross-Section Generation for TRIGA Core Analysis."

Engineering Science and Mechanics Department

A.Y. Kang, Electron Spin Resonance observation of trapping centers in the high ? hafnium oxide system. May 2004. Advisor: Patrick M. Lenahan

X. Liu, Jung Yul Lim, Henry J. Donahue, Erwin A. Vogler. Influence of Substratum Surface Hydrophilicity/ Hydrophobicity on Osteoblast Adhesion, Morphology, and Focal Adhesion Assembly. Biomaterials, submitted.

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), High School Student (HS)

APPLIED RESEARCH LABORATORY	
Straka, William	F
Welz, Joseph	F

COLLEGE OF AGRICULTURE	
Plant Pathology	
Juba, Jean	S

COLLEGE OF EARTH & MINERAL SCIENCE	
Energy & Geo-Environmental Engineering	
Phelps, Mwita	G
Naraayananm, Beepa	G

COLLEGE OF ENGINEERING	
Civil & Environmental Engineering	
Burgos, William	F
Dempsey, Brian	F
Jang, Je-Hun	PD
Park, Byungtae	G
Computer Science & Engineering	
Alim, Fatih	G
Degalahal, Vijay	G
Irwin, Mary Jane	F
Narayanan, V.	F
Xie, Yuan	F
Engineering Science & Mechanics	
Hawk, Gavin	G
Kang, Andrew	G
Lenahan, P.	F
Mechanical & Nuclear Engineering	
Adamonis, Jaclyn	U
Azmy, Yousry	F
Bachman, Ben	U
Bernecker, Aaron	U
Brenizer, Jack	F
Bryan, Mac	S
Catchen, Gary	F
Cetiner, Sacit	G
Chang, Jong	G

Mechanical & Nuclear Engineering	
Chaung, Abel	G
Cimbala, John	F
Connelly, Saray	U
Daubenspeck, Thierry	S
Davison, Candace	S
Decker, Chanda	U
Edwards, Bob	F
Flinchbaugh, Terry	S
Hauck, Danielle	G
Heidrich, Brenden	F
Heller, A. Kevin	G
Hochreiter, Larry	F
Hoover, Jared	U
Ivanov, Kostadin	F
Kinney, Brian	U
Koziol, Adam	U
Kriangchaiporn, Natekool	G
LoVerde, Bianca	U
Marcy, Melisa	U
McCullough, Randy	S
Mench, Matt	F
Miller, Doug	U
Morlang, G. Michael	G
Motta, Arthur	F
Palacios, Fernando	U
Pekula, Nick	G
Portanova, Alison	S
Pye, Brian	U
Rankin, Paul	S
Rickert, Bret	U
Sears, C. Frederick	F
Shields, Dan	G
Skilone, Dan	U
Slaybaugh, Rachel	U
Soung, Stephen	U
Talley, Ashley	U
Tippayakul, Chanatip	G
Tobin, Dan	G
Todorova, Nadejda	G
Tracey, Michael	U

Mechanical & Nuclear Engineering	
Trivelpiece, Cory	G
Turhan, Ahmet	G
Tyree, Chris	G
Ünlü, Kenan	F
Vijaykrishnan, N.	G
Vincenti, John	S
Wilmot, Aaron	U
Yilmaz, Serkan	G
Zerr, Robert	U

COLLEGE OF LIBERAL ARTS	
Anthropology	
Bondar, Greg	G
Fleming, J.	U
Hirth, K.	F

COLLEGE OF SCIENCE:	
Biochemistry	
Bollinger, M.J., Jr.	F
Guyer, R.B.	S
Krebs, Carsten	F
Price, J.C.	G
Saleh, L.	G
Stone, K.	G
Biology	
Ma, Hong	F
Li, Wuxing	G
Chemistry	
Allcock, Harry	F
Chalkova, Elena	S
Gerlach, Denise	U
Phelps, Mwita	G
Materials Sciences & Engineering Dept.	
Liu, Xiaomei	G
Ravi, Dhurjati	G
Vogler, Erwin	F
Physics	
Barzilov, Alexander	F
Sokol, Paul	F

OFFICE OF ENVIRONMENTAL HEALTH AND SAFETY	
Bertocchi, Dave	S
Boeldt, Eric	S
Hermann, Greg	S
Linsley, Mark	S
Morlang, Suzanne	S
Wiggins, Jim	S

INDUSTRIES, ETC.	
ADP Life Services	Roy Hammerstedt
Clarion University	Frank Vento
COGEMA	Gilles Bonnet Jean-Franciose Giraldi Jean Oudut Laurent Stachetti
Cornell University	Mark Dinert
David Martin	David Martin
Eagle-Picher	Monte Hart Jerry Houdyshell Sandi Rushin
Exelon	Nelson Heddle Milton Mui
Fairchild Corporation, Mountaintop	Joe Macieunas
Fairchild Corporation, South Korea	Jiwall Joung
General Motors	Eric Thompson Tom Trabold Lee Whitehead
Lockheed Martin	Alex Bogorad Larry Bruccoliere Steve Moyer
NETCO (Northeast Technology Corporation)	S. Levenroth Ken Lindquist Doug Vonada
Northrup-Grumman (formerly TRW)	Frank Cornell Don Randall
Novax, Inc.	John Knell
NWT	Jerre Palino
Physical Acoustics	Weiming Dai Jim Esposito
Primasep	Charles Coleman
Raytheon Company, Sudbury, MA	Bruce Black Jacques Casteel
Raytheon Systems Company, El Sequndo, CA	Ed Craig
Raytheon, St. Petersburg, FL	Craig Uber
Richard Gazzini	Richard Gazzini
SAIC	Ed Draper
Suntronics	David Ripley
Syngenta Crop Protection	Leslie Berger
Toyota	Kiyoshi Byokota Katsuhiko Kinoshita Kazuki Kuwabara Seiichi Matsumoto Chao-Yang Wang Yasuhiro Yamamoto
TRACERCO	Mike Boone
Tru-Tec	Mike Flinniken Eric Growney
University of Pittsburgh, Greensburg	Hollie Ramaley Tim Savisky Ted Zaleskiewicz
Westinghouse Science and Technology Center	Abdul Dulloo Frank Ruddy

APPENDIX B
Formal Tour Groups

Group Name	Date	# Visitors
MNE	07/02/03	1
Power Plant	07/02/03	3
VIEW	07/03/03	22
Scalacs	07/07/03	1
PGSAS	07/07/03	26
Personal	07/07/03	1
PGSAS	07/08/03	42
TRAC	07/08/03	5
AAR	07/09/03	2
Kurchatov Institute	07/09/03	1
Personal	07/14/03	1
Teacher Workshop	07/14/03	14
Teacher Workshop	07/15/03	14
Teacher Workshop	07/16/03	14
Slice of Science	07/17/03	10
TRS Technologies	07/17/03	3
PSNES Representative	07/17/03	1
Westinghouse	07/18/03	2
Spend a Summer Day	07/21/03	6
Spend a Summer Day	07/21/03	6
Soil and Crop Department	07/22/03	1
Physics Department	07/23/03	1
Student	07/23/03	1
Medical Physics	07/23/03	1
Personal	07/24/03	2
Spend a Summer Day	07/25/03	4
Spend a Summer Day	07/28/03	7
Sear-Brown	07/29/03	1
BMB	07/29/03	1
Sear-Brown	07/30/03	1
Prospective Student	07/31/03	3
Spend a Summer Day	08/01/03	2
BMB	08/04/03	1
Warner Review	08/06/03	2

Group Name	Date	# Visitors
Chemistry Department	08/07/03	2
Police Services	08/08/03	1
Police Services	08/08/03	1
Animal Resources	08/13/03	1
General Motors	08/13/03	1
Personal	08/15/03	1
Personal	08/15/03	3
II-VI Products	08/18/03	17
Grier School	08/19/03	1
Personal	08/19/03	1
Manufacturing Sciences	08/20/03	1
University Police	08/25/03	1
College of Engineering	08/27/03	1
Personal	08/29/03	1
Visiting Student	09/08/03	1
PADEP	09/08/03	1
Pathfinder Fuel Group	09/09/03	8
Central VA Governor's School	09/12/03	18
Parents Weekend Open House	09/13/03	196
NucE 401	09/22/03	6
Former Director	09/22/03	1
Engineering Seminar	09/22/03	13
College of Engineering	09/23/03	1
Houserville Elementary	09/25/03	81
Former Student	09/26/03	1
Computer Science & Engineering	09/30/03	2
NucE 301	10/01/03	28
CNSC	10/02/03	2
Geology	10/06/03	1
NucE 401	10/14/03	7
Health Physics	10/14/03	7
RPO Roundtable	10/15/03	3
PPL	10/20/03	1
DOE	10/22/03	6

APPENDIX B
Formal Tour Groups

Group Name	Date	# Visitors
Primasep	10/23/03	1
Los Alamos National Lab	10/27/03	1
Personal	10/27/03	1
Personal	10/31/03	2
PSRSC Audit	11/03/03	1
Bettis	11/04/03	1
Mistler	11/04/03	2
WISER	11/05/03	1
ME Professor	11/05/03	1
NRC	11/05/03	1
Ligonier Valley	11/06/03	39
Virginia Tech	11/07/03	1
Prospective Student	11/08/03	21
ME Professor	11/10/03	1
Food Science	11/13/03	13
Former Student	11/14/03	1
Prospective Student	11/17/03	2
ME 33	11/18/03	5
ME 33	11/18/03	2
ME 33	11/20/03	6
ME 33	11/20/03	5
Biology	11/21/03	1
Prospective Student	11/25/03	2
Penn Tech College	11/25/03	23
Former Employee	11/26/03	1
Framatome ANP	11/26/03	1
ME 33	12/02/03	5
ME 33	12/02/03	2
EASI House	12/02/03	17
IE 408W	12/03/03	21
ME 33	12/04/03	3
IE 408W	12/04/03	22
IE 408W	12/05/03	20
NucE 310W	12/08/03	2

Group Name	Date	# Visitors
NucE 401	12/09/03	6
ECS	12/10/03	2
University Police	12/11/03	1
Grier School	12/12/03	1
Police Services	12/18/03	1
Police Training	12/22/03	18
NRC	01/08/04	2
M&NucE	01/09/04	1
Police Training	01/09/04	20
BMB	01/12/04	2
Freshman Seminar	01/13/04	9
Toyota	01/13/04	5
University Pitt Greensburg	01/14/04	2
Personal	01/14/04	1
Student	01/15/04	1
WISER	01/15/04	2
BMB	01/16/04	4
NucE 450	01/20/04	15
Personal	01/20/04	1
Physics Department	01/21/04	1
NucE 450	01/22/04	13
Interns	01/22/04	2
Dean's Office	01/27/04	1
M&NucE	01/27/04	1
ME Student	01/27/04	1
M&NucE	01/29/04	2
Personal	01/31/04	3
M&NucE	02/02/04	1
Computer Science & Engineering	02/02/04	3
Student	02/04/04	1
Seminar Speaker	02/05/04	3
Student	02/06/04	1
Dean's Office	02/10/04	2
M&NucE	02/10/04	1

APPENDIX B
Formal Tour Groups

Group Name	Date	# Visitors
Greg Downing	02/13/04	1
Personal	02/16/04	3
Jr Science Museum	02/19/04	20
Brockway High School	02/20/04	15
Blue Chip Recruits	02/21/04	3
Personal	02/24/04	1
STS Interest House	02/24/04	4
NRC Exit Interview	02/27/04	1
Lock Haven	02/28/04	9
Engineering Open House	02/28/04	14
Open House	02/28/04	14
Engineering Open House	02/28/04	46
Engineering Open House	02/28/04	25
Engineering Open House	02/28/04	9
Bald Eagle High School	03/02/04	14
PSU Ambulance	03/02/04	8
Fuel Cell Group	03/18/04	1
Seminar Speaker	03/18/04	1
Spring Grove High School	03/19/04	1
Girl Scouts	03/20/04	26
Cornell University	03/22/04	1
PAJSHS	03/22/04	6
Student	03/23/04	1
Altoona Chemistry	03/23/04	8
Seminar Speaker	03/25/04	1
Personal	03/25/04	1
Prospective Student	03/29/04	2
Student	03/29/04	1
Tyrone Middle School	03/30/04	41
Tyrone Middle School	03/30/04	10
EMS	04/01/04	1
Lycoming College	04/01/04	10
Personal	04/01/04	1
Personal	04/01/04	2

Group Name	Date	# Visitors
ECS	04/06/04	1
Student	04/07/04	1
Bettis and Naval Research	04/08/04	5
Cornell University	04/08/04	1
Prospective Student	04/08/04	6
Greensburg-Salem High School	04/13/04	14
Student	04/13/04	1
Student	04/13/04	3
Berwick High School	04/14/04	9
Computer Science & Engineering	04/15/04	1
Student	04/16/04	2
Personal	04/16/04	1
Student	04/16/04	1
OEA	04/19/04	1
Physics Department	04/20/04	1
Wyomissing	04/21/04	4
Take Your Daughters & Sons to Work	04/22/04	16
Take Your Daughters & Sons to Work	04/22/04	16
Take Your Daughters & Sons to Work	04/22/04	13
Royal Navy	04/22/04	9
Centre County Sheriff	04/23/04	2
Personal	04/26/04	1
Camp Hill High School	04/26/04	13
Williamson High School	04/27/04	26
Punxsutawney High School	04/28/04	8
Personal	04/29/04	1
Bedford High School	04/30/04	26
ME30H	04/30/04	4
Moshannon Valley Jr/Sr High School	05/06/04	36
Personal	05/10/04	2
Geography	05/11/04	1
Engineering Services	05/12/04	1
Bald Eagle High School	05/15/04	1
IST and Bechtel	05/17/04	5

APPENDIX B
Formal Tour Groups

Group Name	Date	# Visitors
Kane High School	05/17/04	27
Mifflin Co. Christian	05/18/04	17
ECS	05/18/04	1
PJAS	05/18/04	3
Spring Grove High School	05/19/04	16
Personal	05/19/04	2
IB Davison Middle School	05/20/04	17
Bettinenn HS Science Olympaid	05/20/04	27
Personal	05/21/04	4
Personal	05/25/04	2
Unlu Meeting	05/27/04	1
Personal	06/07/04	2
Prospective Student	06/11/04	3
Personal	06/15/04	1
KAERI	06/21/04	3
High School Teacher	06/22/04	1
Research Undergraduate Experience	06/23/04	22
Student	06/23/04	1
VIEW Group	06/24/04	28
PSU Grad Student	06/28/04	1
EMS	06/28/04	1
WISE Group A	06/30/04	16
WISE Group B	06/30/04	16
TOTAL		1697

* 186 other individuals visited the facility but did not partake in a formal tour (i.e., caterers, physical plant supervisors, human resource reps, office maintenance personnel, vendors, etc.)