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Radiation Science and Engineering Center
College of Engineering
The Pennsylvania State University
Breazeale Nuclear Reactor Building
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Annual Operating Report, FY 01-02
PSBR Technical Specifications 6.6.1
License R-2, Docket No. 50-5

December 17, 2002

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, 2001 through June 30, 2002, 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-Seventh 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

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PENN STATE BREAZEALE REACTOR

Annual Operating Report, FY 01-02
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, 2001 and June 30, 2002, the PSBR was

critical for	1028 hours	or 3.8 hrs/shift
subcritical for	424 hours	or 1.5 hrs/shift
used while shutdown for	529 hours	or 2.0 hrs/shift
not available	54 hours	or 0.2 hrs/shift
Total usage	2035 hours	or 7.5 hrs/shift

The reactor was pulsed a total of 124 times with the following reactivities:

< $2.00	10
$2.00 to $2.50	101
> $2.50	13

The square wave mode of operation was used 52 times to power levels between 100 and 500 KW.

Total energy produced during this report period was 648 MWH with a consumption of 33 grams of U-235.

Unscheduled Shutdowns - Tech Specs requirement 6.6.1.b.

The three unplanned shutdowns during the July 1, 2001 to June 30, 2002 period are described below.

October 4, 2001 - The reactor operator scrammed the reactor as per procedure upon the receipt of a Rabbit I Radiation High Alarm while a rabbit sample was in the reactor core. An investigation revealed that the SRO had returned the system's radiation monitor to the X1 instead of the required X100 range after checking out the monitor. The monitor had responded to normal

Argon-41 levels expected when the system is operated. A red arrow was placed at the X100 setting to reinforce the proper setting.

November 7, 2001 – Reactor Safety System (RSS) Fission Chamber Power High Scram about one hour into a reactor run with a sample in the central thimble of the reactor core. Historical trends investigation revealed no spikes or power changes on any channel. Scram points were verified to be correct.

April 11, 2002 – Reactor Safety System (RSS) and DCC-X Computer Fission Chamber Power High Scrams 27 minutes into a 54 minutes reactor run with a sample in the central thimble of the reactor core. Historical trends investigation revealed no spikes or power changes on any channel.

Major Maintenance With Safety Significance - Tech Specs requirement 6.6.1.c.

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

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

Facility Changes -

July 17, 2001 - AP-12, Change, procedure completed for the switchover of the Reactor Safety System (RSS) Wide Range Channel from a GIC detector on the east side of the reactor core to a GIC detector located at the rear of the reactor core. This location makes the detector response more independent of rod position, gamma buildup, and reflected gammas from experimental facilities. A staff review indicated that the change did not present any safety issues related to the SAR.

September 26, 2001 – AP-12, Change, procedure completed to change the alert points on the Reactor Bridge East, Reactor Bridge West, and the Pool Wall South radiation monitors from 30 mR/hr to 50 mR/hr. With the return of reactor operations from 800 kW to 1000 kW, there were occasional alerts on the Reactor Bridge West monitor at powers above 800 kW with the alert at 30 mR/hr. For consistency, the alert points were changed to 50 mR/hr on all three monitors. The alarm points remained at 200 mR/hr for all three monitors. A staff review indicated that the change did not present any safety issues related to the SAR.

October 22, 2001 - AP-12, Change, procedure completed to install an Evacuation Alarm Remote Silence System. This was done to allow for improved communications during building re-entry when an evacuation alarm is present. The silence system can only operate when a building evacuation alarm condition is present. The silence system is actuated by use of an A key (SRO only) at a panel in the westwing stairwell. The silence is effective for 15 minutes (or less if the alarm condition clears). If the alarm condition still exists after 15 minutes, the system can be actuated for another 15 minutes, etc. A staff review indicated that the change did not present any safety issues related to the SAR.

December 11, 2001 - AP-12, Change, procedure completed to change the alert set points for the Reactor Bay East Air Monitor and the Reactor Bay West Air Monitor. This was done to decrease the frequency of nuisance alerts due to radon. The alert points were increased from 3.78 decades (6025 cpm) to 3.85 decades (7080 cpm). The deadband was also changed from 0.06 to 0.15 decades so that when an alert occurs, the alert will remain locked in. The alarm points remain at 4 decades. A staff review indicated that the change did not present any safety issues related to the SAR.

Procedures -

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

New Tests and Experiments -

None

Radioactive Effluents Released - Tech Specs requirement 6.6.1.e.

Liquid

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

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

Gaseous

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

The amount of Ar-41 released from the reactor pool is very dependent upon the operating power level and the length of time at power. The release per MWH is highest for extended high power runs and lowest for intermittent low power runs. The concentration of Ar-41 in the reactor bay and the bay exhaust was measured by the Radiation Protection staff during the summer of 1986. Measurements were made for conditions of low and high power runs simulating typical operating cycles. Based on these measurements, an annual release of between 491 mCi and 1490 mCi of Ar-41 is calculated for July 1, 2001 to June 30, 2002, resulting in an average concentration at ground level outside the reactor building that is 0.8 % to 2.4 % 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 369 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 369 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 3.0 %.

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 64 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 46242 pCi/l (the average for July 1, 2001 to June 30, 2002) the tritium activity released from the ventilation system would be 819 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	819 μC
Average concentration, unrestricted area	1.3 x 10^{-13} μCi/ml
Permissible concentration, unrestricted area	1 x 10^{-7} μCi/ml
Percentage of permissible concentration	1.3 x 10^{-4} %
Calculated effective dose, unrestricted area	6.5 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, 2001 to June 30, 2002 period.

	3rd Qtr '01	4th Qtr '01	1st Qtr '02	2nd Qtr '02	Total
Fence North	30.9	21.6	30.6	24.7	107.8
Fence West	29.4	26.0	27.8	25.9	109.1
Fence East	30.4	28.8	31.9	25.2	116.3
Fence South	28.6	26.8	27.4	24.3	107.1
Control	27.7	25.2	28.6	23.8	105.3
Control	27.0	22.6	26.8	21.6	98.0

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.

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Penn State University

Radiation Science and Engineering Center

47th Annual Progress Report

College of Engineering
Breazeale Nuclear Reactor
University Park, PA

December 2002

47th Annual Progress Report

Penn State Radiation Science and Engineering Center

July 1, 2001 to June 30, 2002

Submitted to:

United States Department of Energy

and

Penn State University

By:

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

December 2002

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U.Ed.ENG 03-30

Penn State is committed to affirmative action, equal opporunity, and the diversity of its workforce

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PREFACE

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

The Penn State University Radiation Science and Engineering Center's Forty-Seventh Annual Progress Report (July 2001 through June 2002) is submitted in accordance with the requirements of Contract DE-AC07-94ID-13223 between the United States Department of Energy and Bechtel (BWXT Idaho), and their Subcontract C88-101857 with The Pennsylvania State University. This report also provides the University administration with a summary of the utilization of the facility for the past year.

Numerous individuals are to be recognized and thanked for their dedication and commitment in this report, especially Sue Ripka who edited the report. Special thanks are extended to those responsible for the individual sections as listed in the table of contents and to the individual facility users whose research summaries are compiled in Section X.

INTRODUCTION

I. INTRODUCTION

MISSION

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:

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 over 2800 visitors during the fiscal year. A complete list of groups hosted is presented in Appendix B.

Reactor utilization continued at a high level. Grams of U-235 fuel consumed was the highest of anytime during the last decade for the second year in a row, reflecting increased reactor operation. Grams of U-235 consumed for the 01/02 year was 33 grams compared to a 10 year average of 19 grams. The hours of use per day for the 01/02 year was 7.5 hours compared to a 10 year average of 6.4 hours.

The 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. Drs. Jack S. Brenizer and John M. Cimbala of the Department of Mechanical and Nuclear Engineering continued a major research project using radioscopy for a Bettis Atomic Power Laboratory project involving fluid dynamics.

Several new companies used the beam facilities for radiography and radioscopy projects.

Phase III of Dr. Robert Edwards' DOE funded project "Monitoring and Control Research Using a University Research Reactor" was completed. This involved considerable staff efforts in interfacing Dr. Edwards' control system with the Penn State Low Presure Integral Test Facility. Significant staff assistance was needed to upgrade the test loop facility.

There was a significant increase in the number of samples irradiated, types of experiments and use of the Gamma Irradiation Facility. The number of sample hours in the GammaCell irradiator increased another 50 percent, following a sevenfold increase the previous year. Most of the irradiations are for university departments other than mechanical/nuclear engineering.

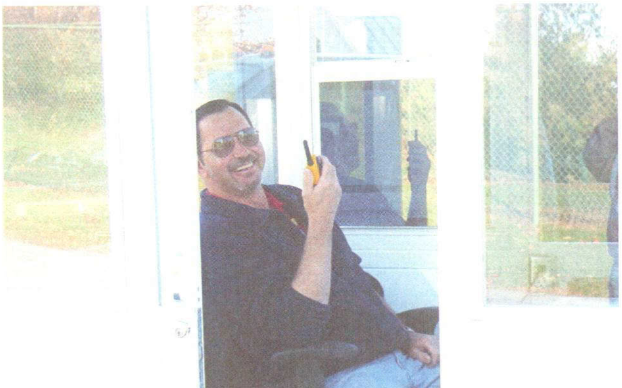
A new Argon-41 production system was designed and built. The new design produces less total system radioactivity for the same amount of isotope delivered to the customer. Irradiation times are shorter and personnel radiation exposure is less than with the previous system.

During June, a complete inspection of all fuel elements, control rods, and control rod drives was completed. The fuel elements with the highest maximum elemental power density and control rods are inspected on a two year cycle. Every four years all elements and control rods are inspected.

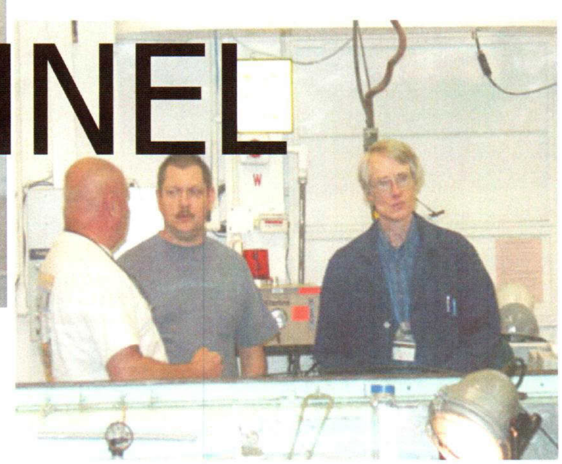
Considerable faculty and staff effort was made in submitting a proposal to DOE for reactor facility upgrades under an INIE (Innovations in Nuclear Infrastructure and Education) grant. Penn State submitted a joint proposal with Purdue University, the University of Illinois and the University of Wisconsin. 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. (After the close of the fiscal year, the Penn State led consortium received approximately $1.97 million, with Penn State's share approximately $1 million. Currently, DOE plans to continue the grant program for four additional years. There should be much to report in the 02/03 annual report as the facility upgrades and program expansions come to fruition).

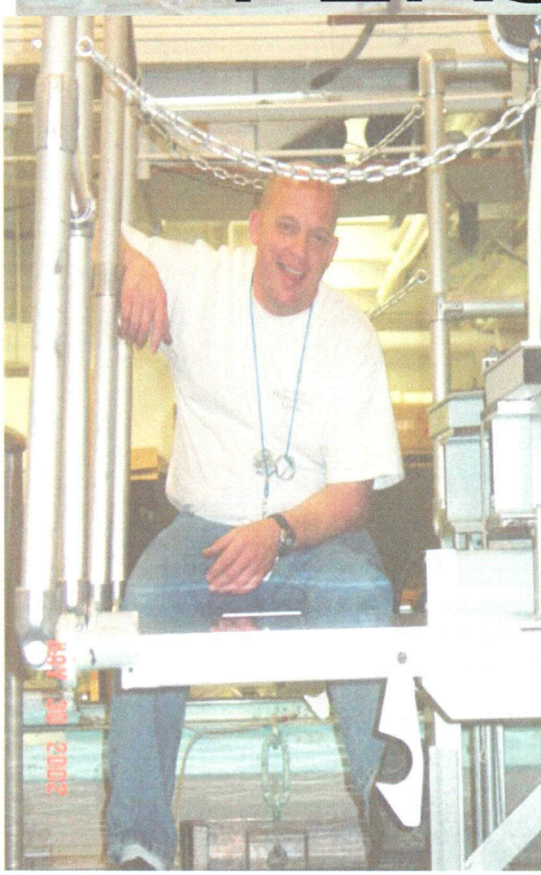
Reactor usage for university courses began to increase this year. Further increases are expected next year as multiple sessions will be needed in the NE 451 and NE 450 laboratory courses. An increased emphasis on graduate students taking NE 444, Nuclear Reactor Operations, will also result in more reactor usage during the next fiscal year.

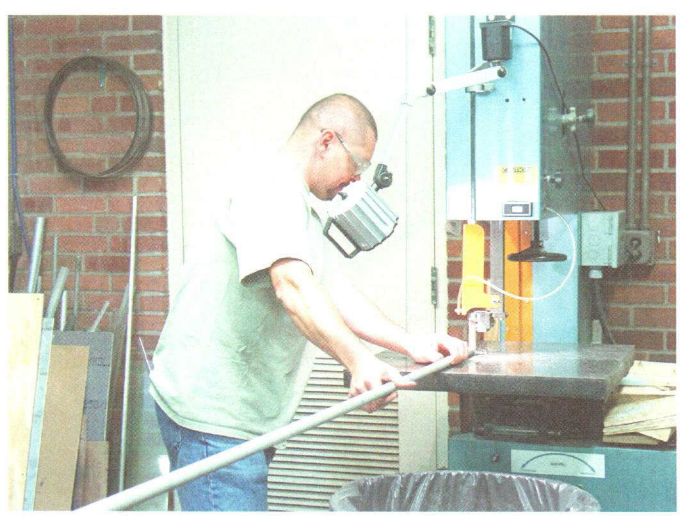
In light of concern for terrorist activities that could be directed against university research reactors, considerable effort was made in expanding the total scope of facility security. Additional attention to security issues is expected to continue, both self-directed and in response to NRC guidance.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



PERSONNEL

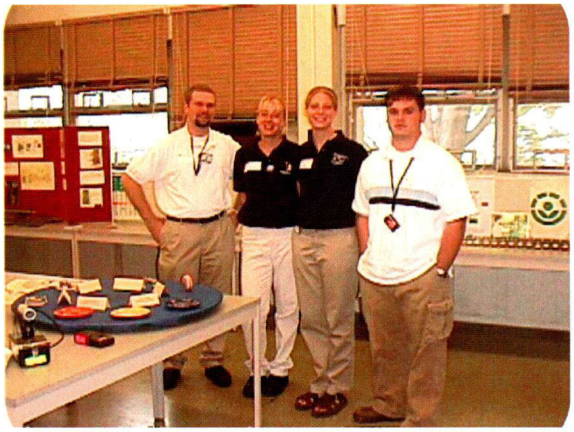






II. PERSONNEL

Many undergraduate students worked in work-study or wage payroll positions during the year. Jaclyn Adamonis, Jennifer Butler, Dianna Hahn, Kaydee Kohlhepp, Melissa Marcy, Tristan Schaefer, and Doug Yocum assisted Candace Davison in facility educational programs for high school students.



Erin Carlin, Joe Bonner, and Gary Meyers worked wage payroll in assisting Candace Davison with educational programs.

Undergraduate Matthew Weirauch worked with Mac Bryan to upgrade local area network software.

Undergraduate Chanda Decker was hired to begin training as a reactor operator in June 2001 and received her operator's license in June 2002.

Randy McCullough was hired on July 7, 2001 as an instrumentation engineer/supervisor reactor operations and received his operator's license in June 2002.

Kenneth Rudy retired on October 31, 2001, after completing 40 years of service at Penn State and 38 years at the Breazeale Reactor.

The following changes to the membership of the Penn State Reactor Safeguards Committee (PSRSC) were effective on January 1, 2002. Committee Chairman Dhushy Sathianathan (assistant professor, engineering graphics, Penn State) completed his second term on the committee and was not eligible for re-appointment. Committee member Larry Hochreiter (professor, mechanical and nuclear engineering, Penn State) became the committee chair. Ali Haghihat (professor, nuclear engineering, Penn State) left the committee and University. Richard Benson (professor and department head, mechanical and nuuclear engineering, Penn State) was re-appointed to a second term. Thomas Litzinger (professor and director of the Leonhard Center, Penn State) was appointed to his first term. Kostadin Ivanov (associate professor in charge of fuel management, Penn State) was appointed to his first term.

TABLE I

Personnel

	Faculty and Staff	Title
*	Francis X. Buschman	Reactor Operator Intern
	Jack S. Brenizer	Professor, Nuclear Engineering
**	Mac E. Bryan	Research Engineer/Supervisor, Reactor Operations
	Gary L. Catchen	Professor, Nuclear Engineering
**	Thierry H. Daubenspeck	Activation and Irradiation Specialist/Supervisor, Reactor Operations
**	Candace C. Davison	Research and Education Specialist/Supervisor, Reactor Operations
*	Chanda C. Decker	Reactor Operator Intern
	Wendy R. Donley	Staff Assistant VI
**	Terry L. Flinchbaugh	Manager, Operations and Training
*	Mark P. Grieb	Engineering Aide
**	Brenden J. Heidrich	Research Assistant
**	Alison R. Portanova	Research and Service Support Specialist/Supervisor, Reactor Operations
	Jana Lebiedzik	Research Support Technician III
**	Gary M. Morlang	Reactor Engineer/Supervisor, Reactor Operations
*	Randy A. McCullough	Instrumentation Engineer
	Jeremy Myers	Computer Support Specialist
	Angela D. Pope	Staff Assistant V
	Paul R. Rankin	Radiation Measurement Technician
	Susan K. Ripka	Administrative Assistant II
	Kenneth E. Rudy	Supervisor of Facility Services (retired)
**	C. Frederick Sears	Director & Affiliate Associate Professor, Nuclear Engineering
**	Dave L. Werkheiser	Reactor Operator Intern

* *Licensed Operator*

** *Licensed Senior Operator*

Technical Service Staff	
Ronald L. Eaken	Machinist A
Sally Thomas	Staff Support

Wage Payroll/Workstudy

Jaclyn Adamonis	Melissa Marcy
Jennifer Butler	Gary Meyers
Joe Bonner	Tristan Schaefer
Erin Carlin	Matthew Weirach
Dianna Hahn	Doug Yocum
Kaydee Kohlhepp	

Penn State Reactor Safeguards Committee

***	R. C. Benson	Professor and Department Head, Mechanical and Nuclear Engineering, Penn State
	E. J. Boeldt	Manager of Radiation Protection, Environmental Health and Safety, Penn State
	T. C. Dalpiaz	Manager, Nuclear Maintenance, Pennsylvania Power and Light Susquehanna Steam Electric Station
*	A. Haghighat	Professor, Nuclear Engineering, Penn State
	L. Hochreiter, Chairman	Professor, Mechanical & Nuclear Engineering, Penn State
**	K. Ivanov	Associate Professor in Charge of Fuel Management, Penn State
**	T. A. Litzinger	Professor and Director of Leonhard Center, Penn State
	I. B. McMaster	Retired Deputy Director, Penn State Breazeale Nuclear Reactor
	G. E. Robinson	Professor Emeritus, Nuclear Engineering, Penn State
*	D. Sathianathan	Assistant Professor, Engineering Graphics, Penn State
	C. F. Sears	Ex-Officio, Director, Penn State Radiation Science and Engineering Center
	R. Tropasso	Manager of Nuclear Design, Exelon

* *Served through January 1, 2002*

** *Initial Appointment January 1, 2002*

*** *Re-Appointed for a second term effective January 1, 2002*

Radiation Science & Engineering Center Personnel Chart

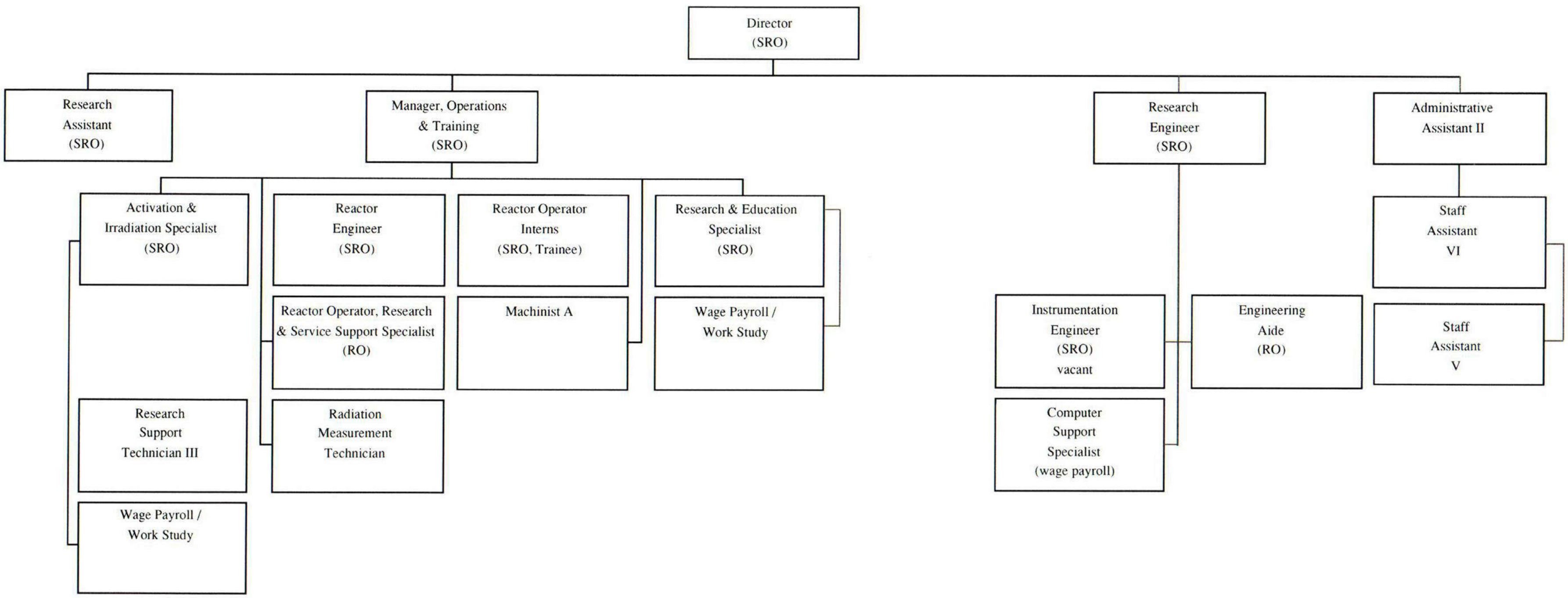
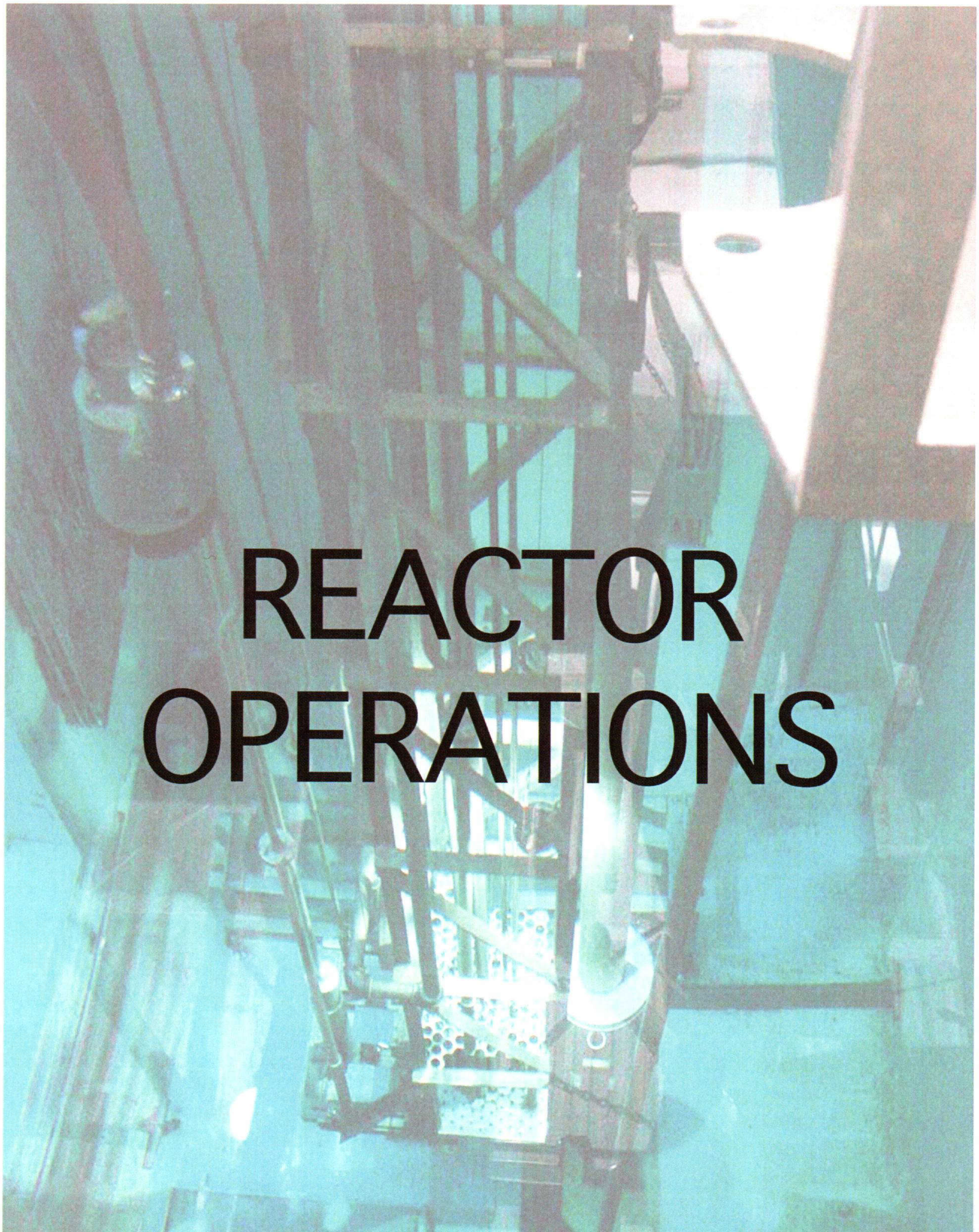


Figure 1


REACTOR
OPERATIONS

III. 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 was capable of operation at a steady state power level of 1000 kW with pulsing capabilities to 2000 MW for short (milliseconds) periods of time.

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

Utilization of the Penn State Breazeale Reactor (PSBR) falls into four major categories:

Educational — *utilization is primarily in the form of laboratory classes conducted for graduate and undergraduate degree candidates and numerous high school science groups. These classes will vary from the irradiation and analysis of a sample, non-destructive examinations of materials using neutrons or x-rays, or transient behavior of the reactor to the calibration of a reactor control rod.*

Research — *involves radionuclear applications, neutron radiography, gamma irradiation, a myriad of research programs by faculty and graduate students throughout the University, and various applications by the industrial sector.*

Training — *programs for PSBR Reactor Operations Staff.*

Service — *involves radionuclear applications, neutron transmission measurements, radioscopy, semiconductor irradiations, isotope production and other applications by the industrial sector.*

The PSBR core, containing about 7.5 lbs. of Uranium-235, in a non-weapons form, is operated at a depth of approximately 18 feet in a pool of demineralized water. The water provides the needed shielding and cooling for the operation of the reactor. It is relatively simple to expose a sample by positioning it in the vicinity of the reactor at a point where it will receive the desired radiation dose. A variety of fixtures and jigs are available for such positioning. Various containers and irradiation tubes can be used to keep samples dry. A pneumatic transfer system offers additional possibilities. A heavy water tank and neutron beam laboratory provide for neutron transmission and neutron radioscopy activities. Core rotational, east-west, and north-south movements provide flexibility in positioning the core against experimental apparatus.

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

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

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

STATISTICAL ANALYSIS

Tables 2 and 3 list Reactor Operation Data and Reactor Utilization Data-Shift Averages, respectively, for the past three years. In Table 2, the Critical time is a summation of the hours the reactor was operating at some power level. The Subcritical time is the total hours that the reactor key and console instrumentation were on and under observation, less the Critical time.

Figure 1. Frank Buschman, Reactor Opertor Intern

Subcritical time reflects experiment set-up time and time spent approaching reactor criticality.

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

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

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

Part B gives a breakdown of the Type of Usage in Hours. The 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.

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

INSPECTIONS AND AUDITS

During October 22 to October 24, 2001, 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 Leo Bobek, director of the University of Massachusetts' Reactor at Lowell. The reactor staff implemented changes suggested by that report, all of which exceed NRC requirements.

Figure 2. RSEC staff conducting fuel inspection (Fred Sears, Terry Flinchbaugh, Candace Davison, and Thierry Daubenspeck (L-R))

TABLE 2

Reactor Operation Data

July 1, 1999 - June 30, 2002

		99-00	00-01	01-02
A.	Hours of Reactor Operation			
	1. Critical	941	864	1028
	2. Subcritical	455	375	424
	3. Fuel Movement	46	0	40
B.	Number of Pulses	75	104	124
C.	Number of Square Waves	28	48	52
D.	Energy Releases (MWH)	419	472	648
E.	Grams U-235 Consumed	22	24	33
F.	Scrams			
	1. Planned as Part of Experiments	11	11	9
	2. Unplanned - Reslting From			
	a) Personnel Action	1	0	1
	b) Abnormal System Operation	1	1	2

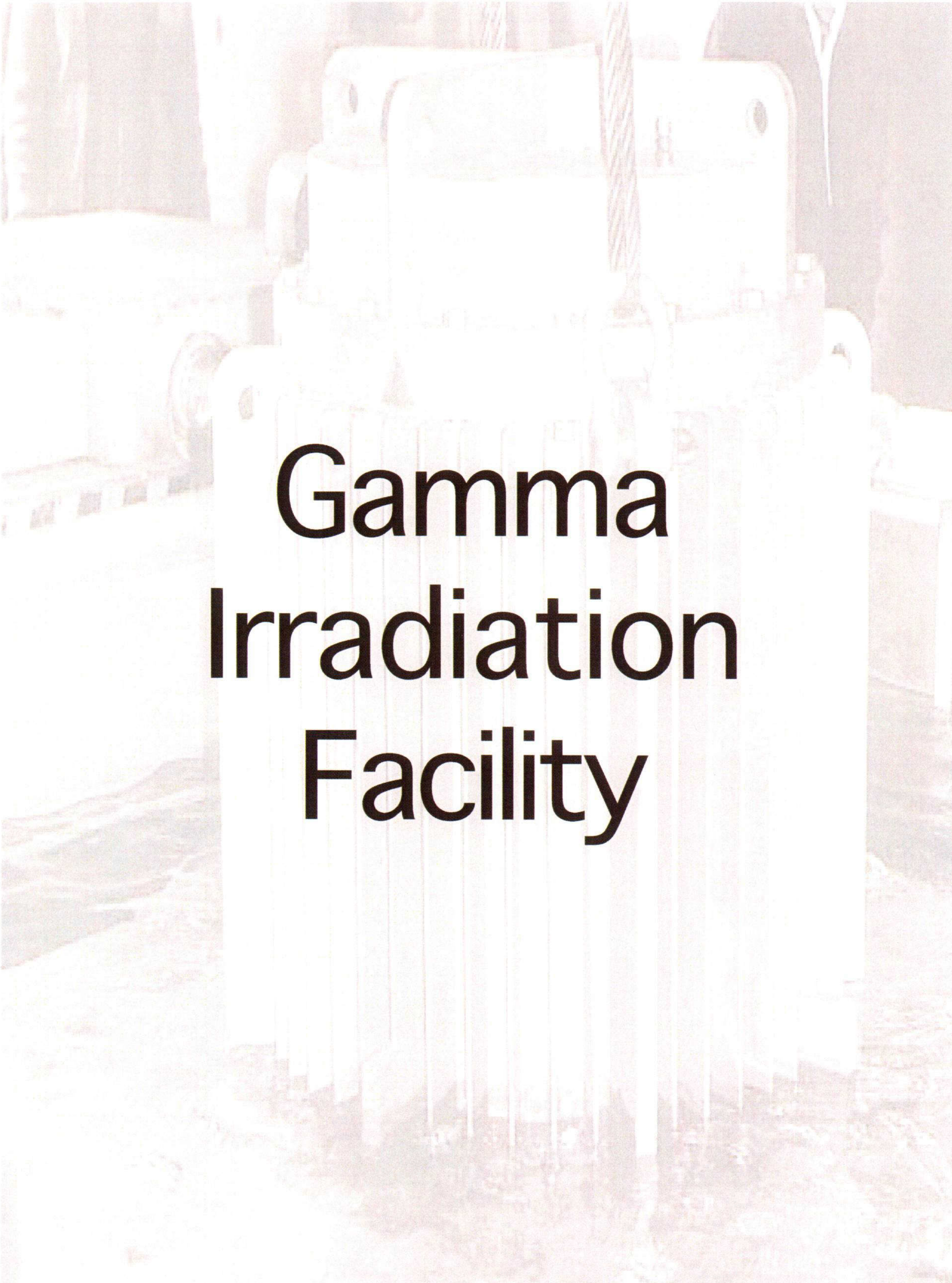
TABLE 3

Reactor Utilization Data

Shift Averages

July 1, 1999 - June 30, 2002

		99-00	00-01	01-02
A.	Reactor Usage			
	1. Hours Critical	3.4	3.2	3.8
	2. Hours Subcritical	1.6	1.4	1.6
	3. Hours Shutdown	1.9	1.6	2
	4. Reactor Not Available	0.1	0.4	0.2
	TOTAL HOURS PER SHIFT	7.0	6.6	7.5
B.	Type of Usage - Hours			
	1. Industrial Research and Service	3.2	3.4	3.5
	2. University Research and Service	0.4	0.6	1.3
	3. Instruction and Training	0.9	1	1.3
	4. Calibration and Maintenance	2.3	1.6	1.3
	5. Fuel Handling	0.2	0	0.1
C.	Users/Experiments			
	1. Number of Users	2.7	2.6	3.1
	2. Pneumatic Transfer Samples	0.1	0.3	1.6
	3. Total Number of Samples	3.0	3.2	4.6
	4. Sample Hours	3.0	2.9	3.4
D.	Number of 8 Hour Shifts	279	270	271



Gamma Irradiation Facility

IV. GAMMA IRRADIATION FACILITY

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

In-Pool Irradiators

For the in-pool irradiators, the source rods are stored and used in a pool 16 feet by 10 feet, filled with 16 feet of demineralized water. The water provides a shield that is readily worked through and allows great flexibility in using the sources. Due to the number of sources and size of the pool, it is possible to set up several irradiators at a time to vary the size of the sample that can be irradiated, or vary the dose rate. Experiments in a dry environment are possible by use of either a vertical tube or by a diving bell type apparatus. Four different irradiation configurations have been used depending on the size of the sample and dose rate required. The advantage of the in-pool irradiators is that the dose rate can be varied in a manner which is optimal for agricultural and life science research.

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 4.

GammaCell 220 Dry Irradiator

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

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

Figure 1. Candace Davison inserts a sample into the GammaCell 220 Dry Irradiator

Use of Gamma Irradiation Services

The use of the Gamma Irradiation facility has been increasing steadily. There was a 50 percent increase in the number of irradiations and sample hours performed in the Gammacell compared to last year. Several departments on campus utilized the services of the Gamma Irradiation facility for a variety of purposes. Figure 2 shows some of the variety of samples and purposes for irradiations this past year. Table 5 compares the past three years' utilization of the Cobalt-60 Irradiation Facility in terms of irradiation time and number of irradiations. Samples requiring over 10 Megarads for cross-linking purposes were typically divided into 5 or 10 Megarad irradiation times to allow for other users.

TABLE 4

Summary of Current Gamma Irradiation Facilities		
Facility	**Maximum Dose Rate in KRads/hour***	**Sample Limitations**
North Tube 6-inch	28.1	Must be less than 6 inches in diameter
South Tube 3-inch	48.3	Must be less than 3 inches in diameter
10-inch Chamber	1.1	Cylinder approximately 10 inches in diameter by 12 inches in height
GammaCell Dry Cell Irradiator	184.8	Cylinder approximately 6 inches in Diameter by 7.5 inches in height
*as of 7/1/2002		

TABLE 5

Cobalt-60 Utilization Data July 1,1999 ñ June 30, 2002							
		99-00	**99-00**	**00-01**	**00-01**	**01-02**	**01-02**
		Pool Irradiator	**GammaCell**	**Pool Irradiator**	**GammaCell**	**Pool Irradiator**	**GammaCell**
A.	Time Involved (Hours)						
	1. Set-Up/Admin. Time	10	21	15	55	17	89
	2. Total Sample Hours	1040	563	1557	3800	394	5667
B.	Numbers Involved						
	1. Total Irradiations	45	118	45	162	33	227
	1. Samples Containers Run[1]	742	383	542	615	204	1200
	2. Different Experimenters	17	23	12	21	5	29
	3. Configurations Used	3	NA	3	NA	4	NA

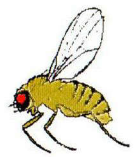
NOTE: The reporting has changed to include the total number of irradiations conducting and the daily averages were eliminated. The sample hours for the GammaCell for 2001-2002 would be equivalent to over 37,000 sample hours in the large pool irradiation Tube.

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

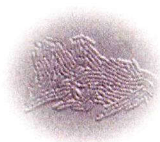
Gamma Irradiation Uses and Examples

Genetic Changes

Poinsettias



Fruit Flies



Cells

Class Projects and Demonstrations:

Beef Patties

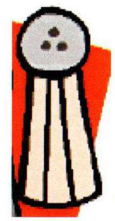
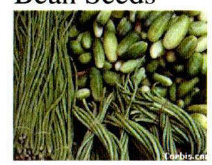


Table Salt

Bean Seeds

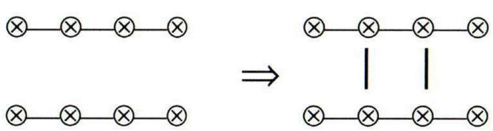


Glass Jars

Mushrooms

Sterilization Medical & Laboratory Products

Cross-Linking of Polymers

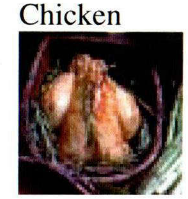


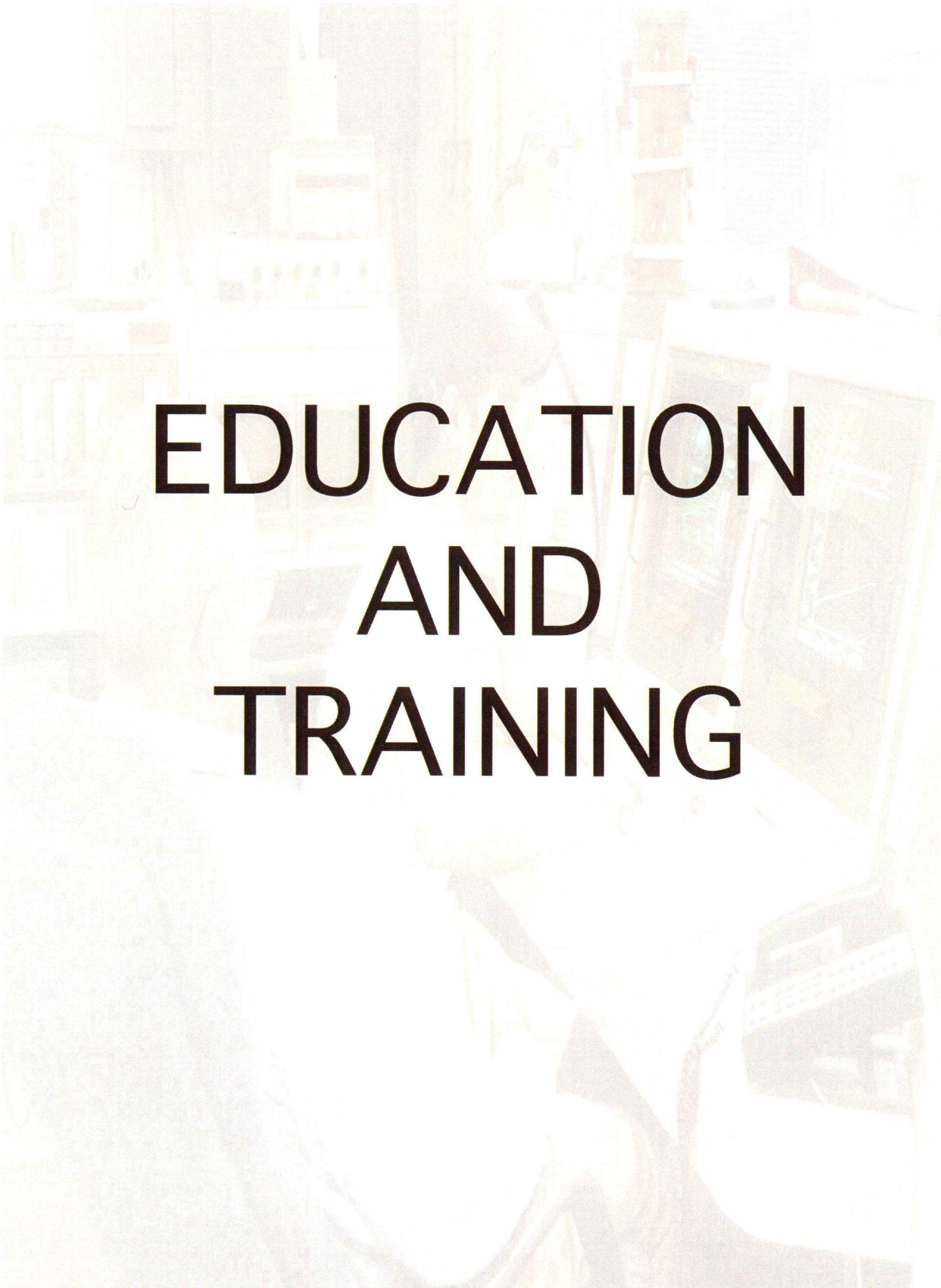
Soil & Leaves for Environmental Research

Food Irradiation

Strawberries

Chicken





EDUCATION AND TRAINING

V. EDUCATION AND TRAINING

During the past year, Penn State's RSEC was used for a variety of educational services, in-house training, formal laboratory courses, and many continuing education programs and tours. The continuing education programs and tours accommodated more than 2,800 visitors.

Operator Training:

The RSEC operating staff has maintained reactor operator competence and safe facility operation through training and requalification. During a two-year training cycle, theory, principles, regulations and actions needed for the safe operation of the reactor facility are covered. Training sessions during the year include lectures, exercises, and other activities. In-house reactor operator requalification during November of 2001, consisted of an oral examination on abnormal and emergency procedures given by T.L. Flinchbaugh and an operating test given by G.M. Morlang. Randy McCullough, instrumentation engineer and Chanda Decker, operator intern passed their NRC Reactor Operator License examinations in June of 2002.

Figure 1. Reactor Operator Training (Fred Sears and Chanda Decker)

Police Training:

In December 2001 and January 2002, a total of 33 University police personnel were given training and retraining sessions by C. C. Davison at the RSEC to ensure familiarity with the facilities and to meet Nuclear Regulatory Commission requirements. Four new University police officers received training in March 2002.

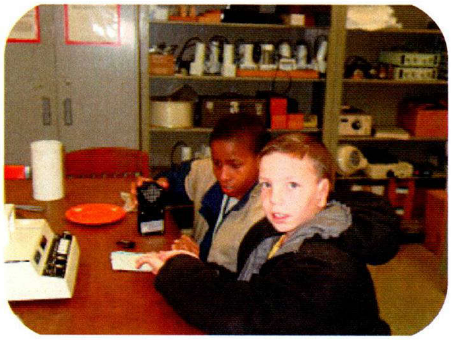
Governor's School:

The sixteenth session of the Pennsylvania Governor's School for Agricultural Sciences (PGSAS) was held at Penn State's University Park campus during summer 2001. Sixty-four high school scholars participated in the five-week program at Penn State. The Governor's School for Agricultural Sciences includes introduction and experience in many different agricultural disciplines. The participants of the Governor's School received a tour of the reactor facility with some time for hands-on instruction. Candace Davison, Chanda Decker, and Gary Meyers provided the instruction and tours for the PGSAS.

Reactor Sharing:

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

More than 800 students and teachers from more than twenty different educational institutions and five colleges came to the RSEC for experiments and instruction (see map). Candace Davison, Jaclyn Adamonis, Tristan Schaefer, Melisa Marcy, Douglas Yocum, and Joseph Bonner were the main instructors for the program. Chanda Decker, Kaydee Kohlhepp and Dianna Hahn along with other mechanical and nuclear engineering students provided information about their major during student visits. Thierry Daubenspeck, Jana Lebiedzik, Mac Bryan, Brenden Heidrich, and Dr. Jack Brenizer provided instruction and technical assistance for experiments.



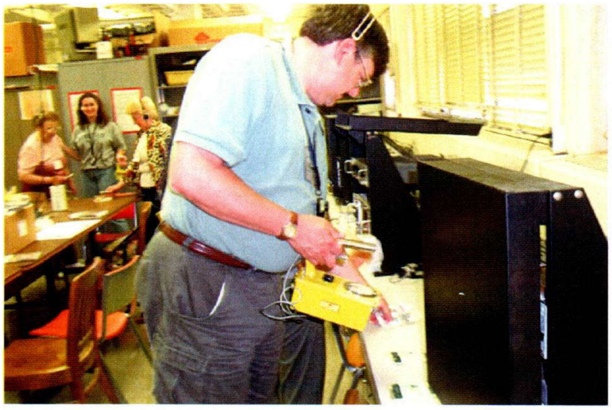
A joint research project with faculty and students from the University of Pittsburgh at Greensburg was conducted during the academic year. Dr. Tim Savisky, assistant professor of natural sciences, and Dr. Ted Zaleskiewicz, professor of physics, along with 2 undergraduate students participated in the project. The main goal was to investigate heavy metal contamination in the environment through Neutron Activation Analysis of tree ring samples.

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, Girls in Engineering, Upward Bound, Pennsylvania Junior Academy of Sciences and other programs associated with campus activities. Several different activities for Girl Scouts and Boy Scouts were conducted at the facility.

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

Nuclear Science & Technology Course

A one-week course on Nuclear Science and Technology was conducted on July 15-20, 2001. John Vincenti was the coordinator of the course which was held again based upon the success of the previous course. Nine teachers attended the workshop and received free Geiger counters through a grant from the American Nuclear Society. Candace Davison provided instruction on radiation, reactor basics, nuclear applications and conducted experiments at the facility for the participants. (see pictures)



ANS/ASME Student Conference:

The student chapter of the American Nuclear Society and American Society of Mechanical Engineers conducted a student conference on April 10-13, 2002, in State College and University Park, PA. A tour of the reactor facility was conducted for more than one hundred interested conference attendees.

Undergraduate Research Scholarships:

Several undergraduate students conducted research at the facility and received scholarship funding from the facility Undergraduate Research Scholarship grant. The purpose of the scholarship is to encourage undergraduate students to participate in investigation and research relating to reactor safety, operations, and utilization. Participation is intended to provide students practical experience in application of radiation science and technology. Students who participated this past academic year included: Dianna Hahn, Kaydee Kohlhepp, Corey Trivelpiece, and Tristan Schaefer. Details about their projects are included in the research section of the report.

Tours:

In addition to the full or half-day programs with experiments, educational tours were conducted for students, teachers, and the general public. All groups, including the those detailed in the above sections, who 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 Parents and Family Weekend, the general public and potential undergraduate or graduate students. More than 475 people participated in open house and "Spend a Day" experiences.

Academic Instruction:

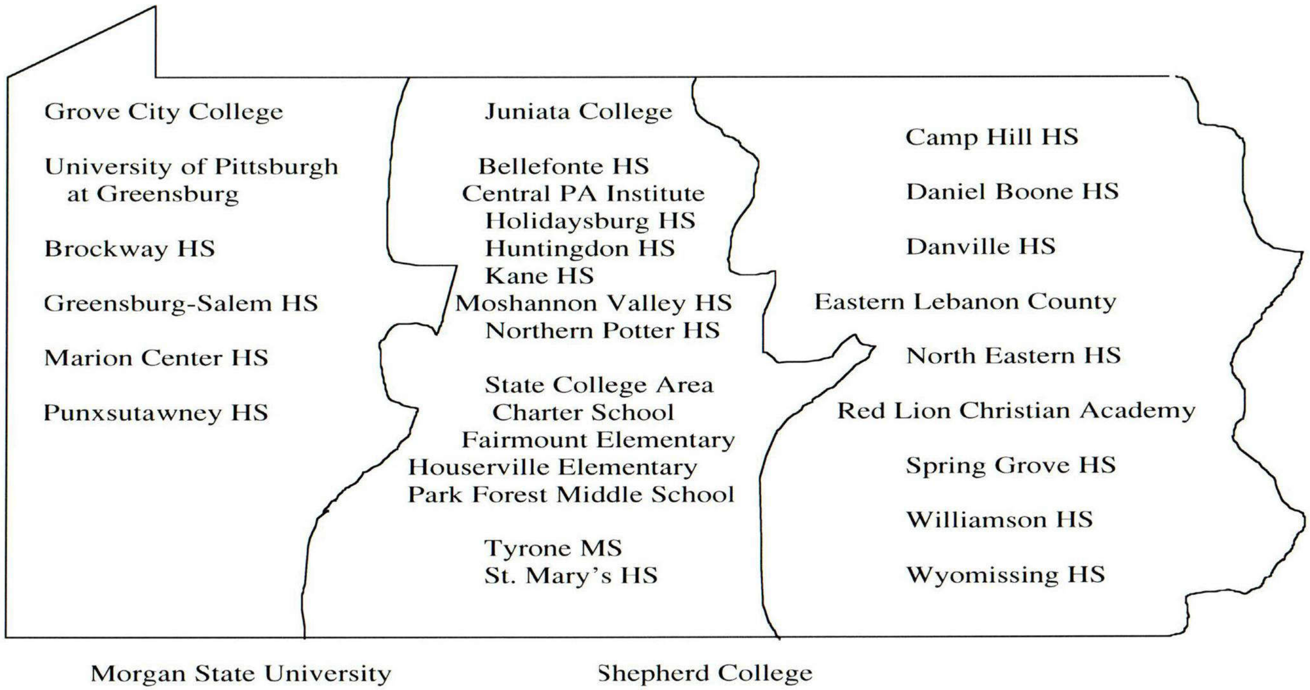
The RSEC supports academic instruction by providing information and expertise on nuclear technology topics, tours, and experiments conducted at the facility and through the availability of specialized equipment and classroom/laboratory space.

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

The reactor classroom was utilized as the base of instruction for several courses including; Freshman seminar -(fall 2001 and spring 2002), 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 following table.

Semester	**Course**	**Instructor**	**Students**	**Hours**
Summer 2001	SCIED 498B – Nuclear Science and Technology Workshop	C.C. Davison J. R. Vincenti	9	4
Summer 2001	RECEP Renewable Energy & Conservation Education Program (Teachers and Students)	C.C. Davison J. R. Vincenti	22	8
Summer 2001	EDG - Leap Program	C.C. Davison	29	2
Fall 2001	NUCE 002S – Freshman Seminar	J. S. Brenizer	20	2
Fall 2001	Nuc E 301 – Fundamentals of Reactor Physics	R.M. Edwards	21	1
Fall 2001	Nuc E 401 – Intro. to Nuclear Engineering	L. Hochreiter	15	3
Fall 2001	NucE 451 – Experiments Reactor Physics	R. M. Edwards	14	26
Fall 2001	Engr 097 - Engineering Seminar	C.F. Sears	15	1
Fall 2001	ENGR 100S - Freshman Seminar	A.J. Baratta	22	1
Fall 2001	Food Science 413 – Sci. & Tech. of Plant Food	R. B. Beehman	24	2
Fall 2001	Food Science /STS 105	V. Chang	9	1
Fall 2001	AG 150S - Agricultural Seminar	D. Olver/L. Sordillo	17	1
Fall 2001	ED 100S - Education Seminar	D. Warren Saxe	16	1
Fall 2001	IE 408 W Human Factors	I. J. Petrick	69	6
Spring 2002	NUCE 001S – Freshman Seminar	J. S. Brenizer	19	2
Spring 2002	NucE 444 – Nuclear Reactor Operations	C. F. Sears	4	46
Spring 2002	NucE 450 – Rad. Detection andMeasurement	J. S. Brenizer	19	8
Spring 2002	ENGR PSY - 432 Engr. Psychology	A. Peck	22	1
Fall 2001	Food Science 415– Sci. & Tech. of Muscle Food	Student Projects	8	2
Spring 2002	IE 408 W Human Factors	D. J. Cannon	76	3
Spring 2002	ME 30	D. A. Santavicca	5	1
Spring 2002	CHEM 036	C.S. Reed	6	1

Educational Institutions Visiting the RSEC



Neutron Beam Laboratory

VI. NEUTRON BEAM LABORATORY

The Neutron Beam Laboratory (NBL) is one of the experimental facilities that is a part of the RSEC. Well-collimated beams of neutrons, thermalized by a D_20 thermal column, are passed into the NBL for use in nondestructive testing and evaluation. Neutron cameras, including several by Precise Optics, Inc., are available for radioscopy (real time radiography). Equipment is available to digitize the real time radiography images for image processing. A photographic laboratory facilitates the development and analysis of static neutron radiographs. Flash radiography utilizing pulsing is also available.

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

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

Projects utilizing the NBL during the year included the following:

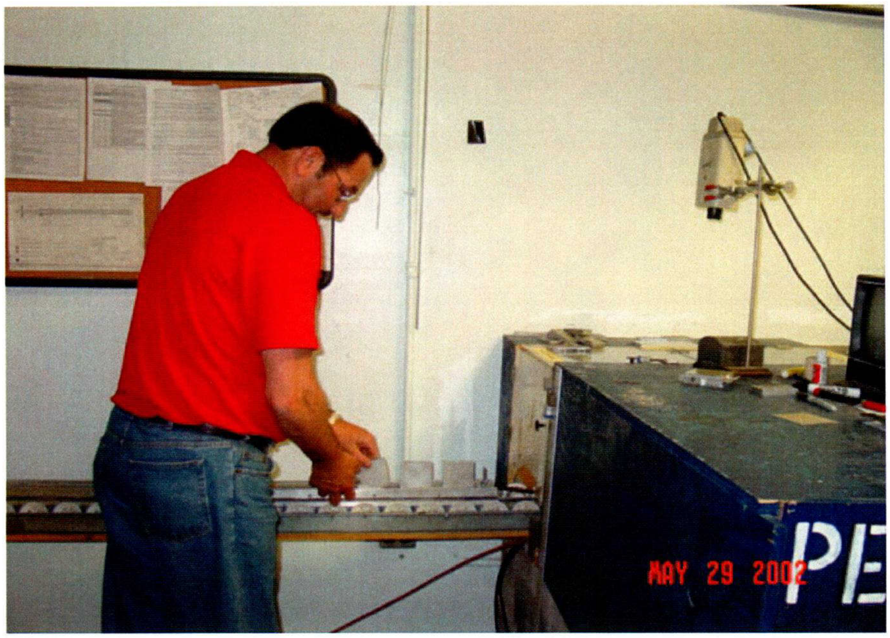
- Bettis Atomic Power Laboratory used the RSEC beginning in June 2000, to evaluate the operational characteristics of an ammonia loop heat pipe. This work resulted in several presented papers.

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

- Radiographic and radioscopic techniques were demonstrated as part of several student projects; including demonstration of neutron and x-ray imaging for the Governor's School students 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.

- A medical device used radiography to examine a stent used in stroke victims.

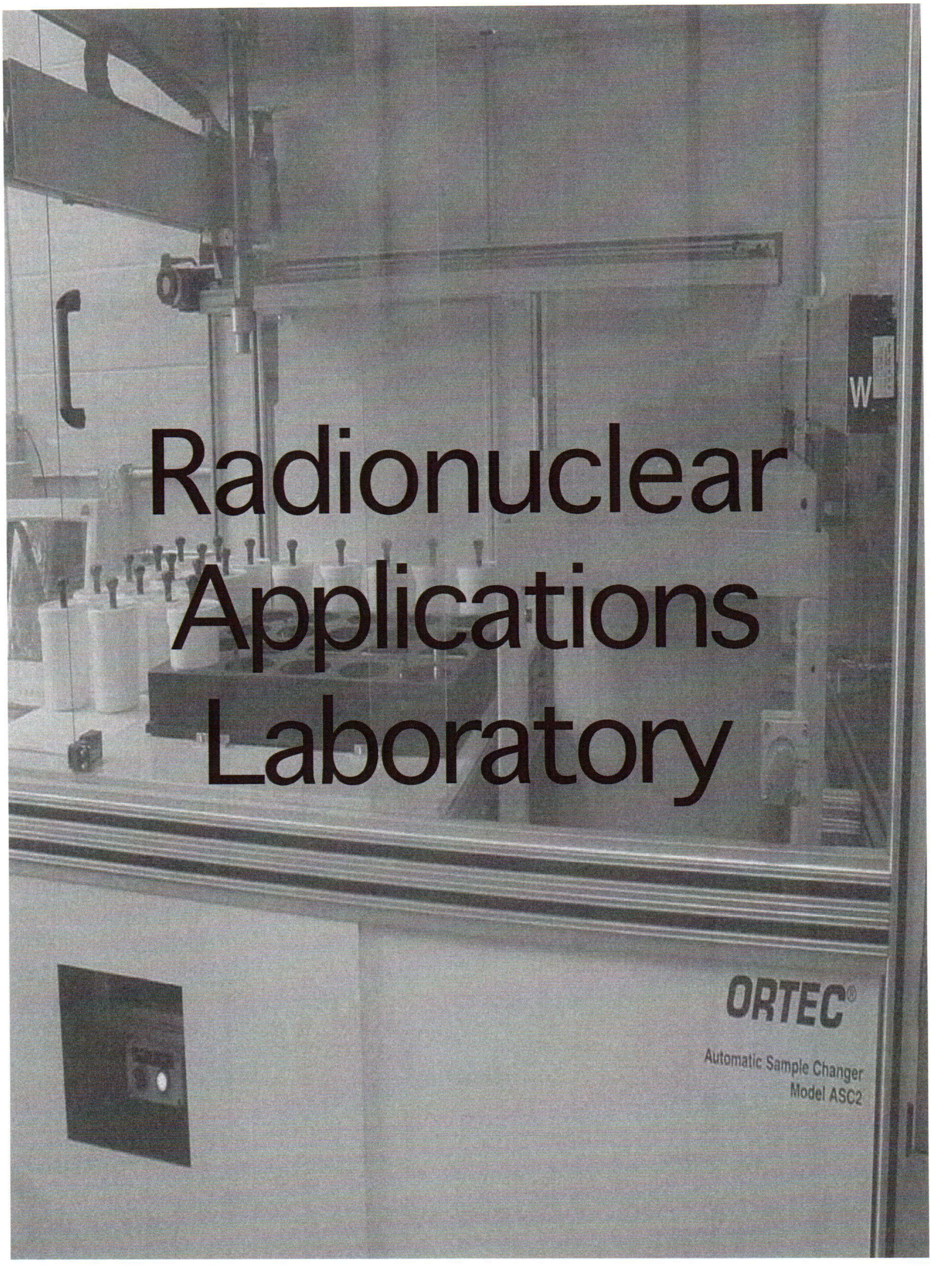
- Work on an ASTM Divergence and Alignment Indicator (DAI) standard was completed. This work resulted in a paper resented at the Fourth International Topical Meeting on Neutron Radiography.



Paul Rankin prepares samples to be exposed to the neutron beam.

- Concrete core samples were examined using neutron radiography to investigate cracking and water retention. This work was performed for a Materials Research Laboratory project.
- Neutron radioscopy was used to determine the hydrogen and boron concentration within metal samples for a Savannah River Laboratory study.

Radionuclear Applications Laboratory



VII. RADIONUCLEAR APPLICATIONS LABORATORY

The Radionuclear Applications Laboratory (RAL) provides consulting and technical assistance to personnel wishing to use radionuclear techniques in their research. The majority of these research projects involve neutron activation; however, the staff also provides services in radioactive tracer techniques, radiation gauging, radiation processing, and isotope production.

Through the analyses of water, air filters, and other environmental samples, RAL personnel support the daily operations of the RSEC. Water used at the facility is sampled a minimum of once per month for various analyses. The reactor pool water is analyzed monthly for gross alpha, beta, and tritium activity. Gamma spectroscopy analysis is performed on these samples on a quarterly basis or as needed. The Cobalt-60 pool water and the heat exchanger are analyzed monthly for alpha/beta activity. Tritium concentrations are also performed for our Deuterium Oxide (D_2O) tank on a monthly basis. The 6,000 gallon holding tank for the pool make-up water is analyzed once each year according to the Office of Radiation Protection requirements.

Last year, 408 semiconductor irradiations were performed at the RSEC for various companies. Devices were received and prepared for irradiation by RAL personnel. After being irradiated, dosimetry pellets were analyzed to determine the 1-MeV Silicon Equivalent fluence received by the devices. Prior to shipping back to the company, gamma spectroscopy is performed on each device to provide a quantitative analysis of the radioisotopes produced. The devices are then returned to the customer in accordance with NRC and DOT regulations.

The facility performed 5 isotope production runs of Na-24, Br-82 or Ar-41 for industrial use during the past fiscal year

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

The RAL assisted students from the anthropology department in characterizing various samples of obsidian and rhyolite using Neutron Activation Analysis. 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 a continuation of work that began years ago.

Figure 1. Thierry Daubenspeck, activation and irradiation specialist, prepares a sample to be irradiated.

The RAL is continuing the process of improving its capabilities by improving upon current systems or, if necessary, designing new systems. One system improvement completed this year is for the irradiation and transfer of argon gas. This improvement resulted in a system that reduces personnel exposure, shortens irrdiation times, and results in lower costs for customers.

The RAL is focusing now on improving the pneumatic transfer system (rabbit system). The current rabbit system does not permit it to be installed while the reactor is operating at any position other than the R1 position. Two items are being investigated: redesign of the in-core terminus to allow the terminus to remain in the reactor core at all times or a second terminus to be constructed for use while the reactor coupled with the Beam Port facilities.

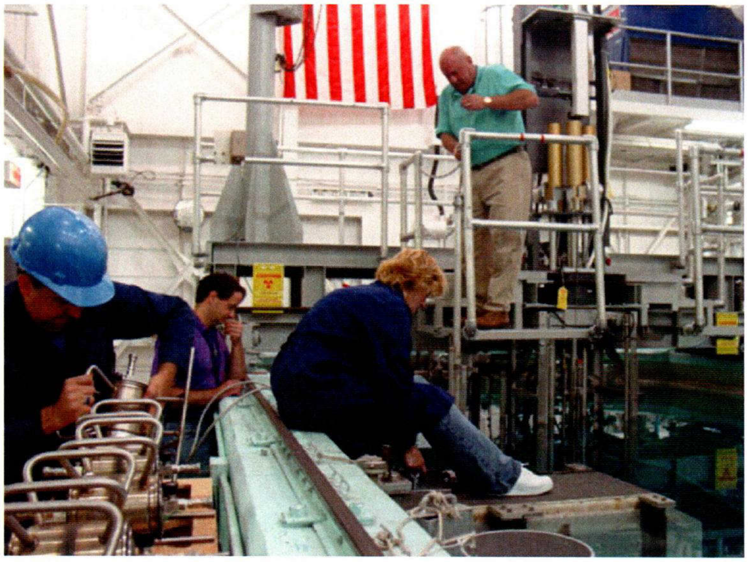


Figure 2. Thierry Daubenspeck, David Bertocchi (health physicist), Alison Portanova, and Mike Morlang prepare for an argon gas transfer (L-R).

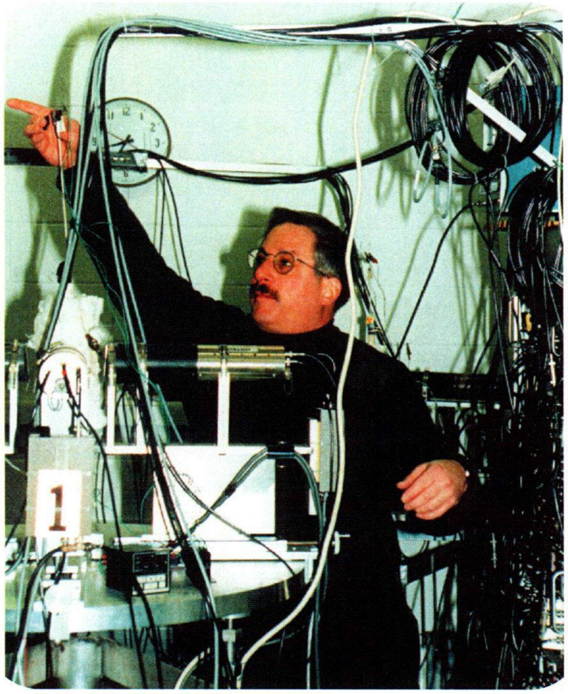
The Angular Correlations Laboratory

VIII. THE ANGULAR CORRELATIONS LABORATORY

The Angular Correlations Laboratory has been in operation for approximately 14 years. The laboratory, which is located in Room 116 and Room 4 of the RSEC, is under the direction of Professor Gary L. Catchen. The laboratory contains three spectrometers for making Perturbed Angular Correlation (PAC) measurements. One apparatus, which has been in operation for 15 years, measures four coincidences concurrently using cesium fluoride detectors. A second spectrometer was acquired 11 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.

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.



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

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

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

Magnetic hyperfine interactions, which can be measured in ferromagnetic and antiferromagnetic bulk and thin-film materials, are used to study the mechanisms that cause the transition between the magnetically-ordered phase and the disordered phase.

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

LOW-PRESSURE INTEGRAL TEST FACILITY

IX. LOW-PRESSURE INTEGRAL TEST FACILITY

I. INTRODUCTION

The Penn State University Low-Pressure Integral Test Facility (LPITF) is a one-half height scaled representation of the General Electric's Simplified Boiling Water Reactor (SBWR). The unique characteristic of the facility is that it was designed, built, and engineered by 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 over the last year. The previous facility design had some problems with the two-phase natural (re)circulation. A new design is 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).

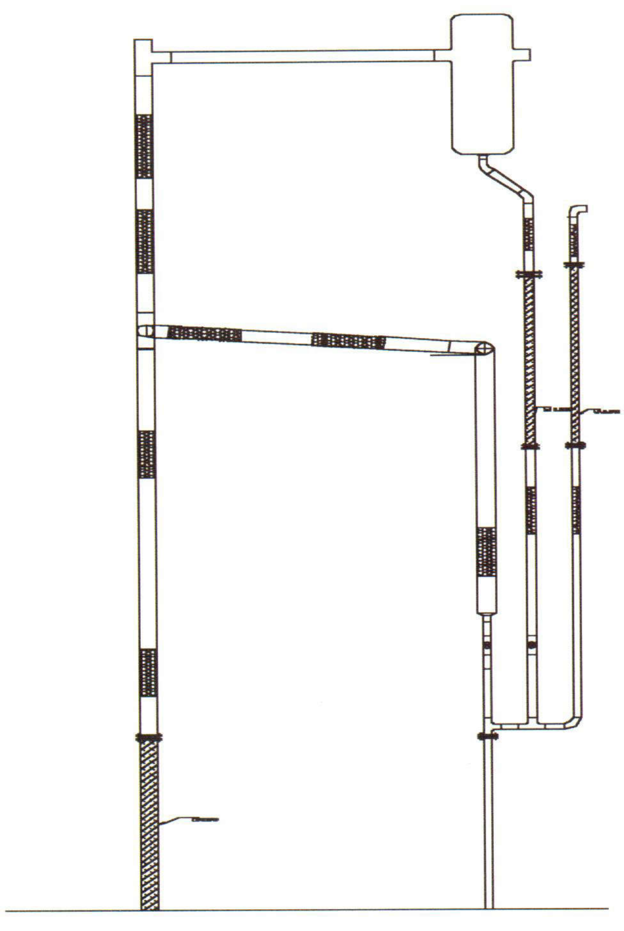


Figure 1 – Detail of the modifications to the downcomer line and crossover leg.

II. 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.

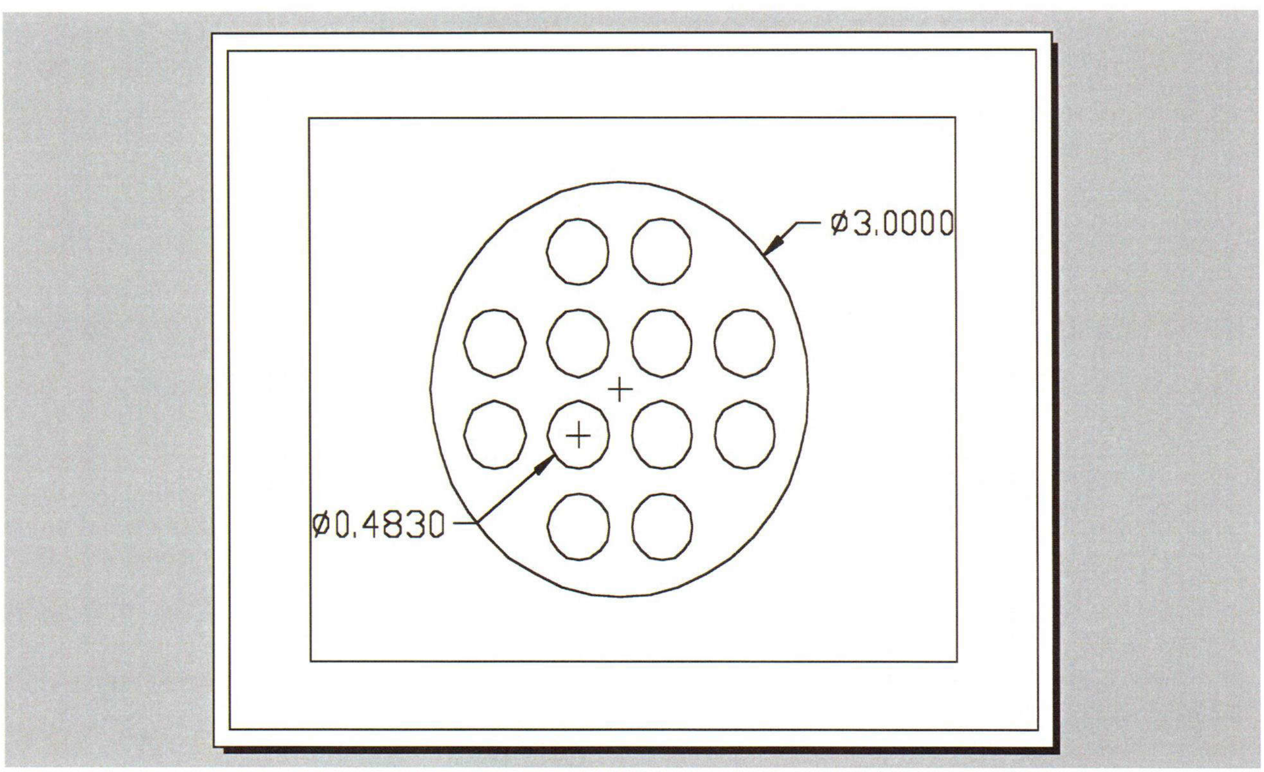


Figure 2 – Core rod layout.

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

III. 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.

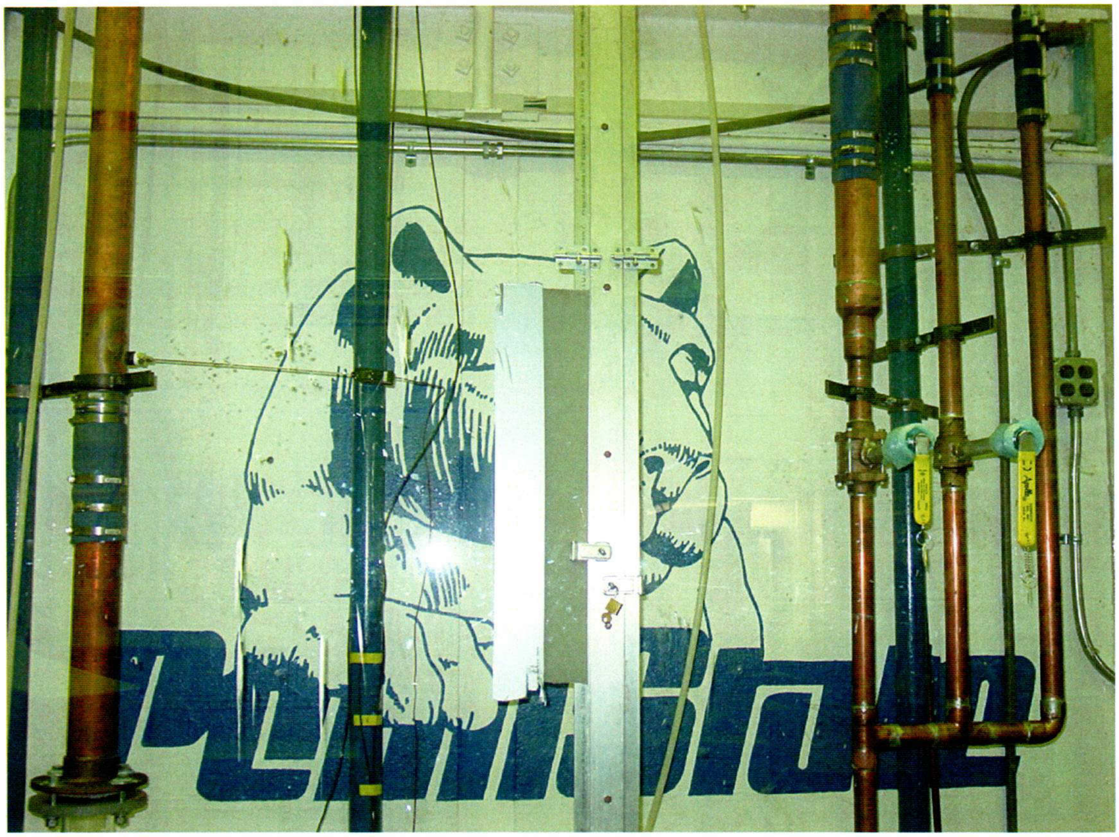


*Figure 4. **Modified downcomer section: This design eliminates flow reversal to the steam separator and/or main condenser.***

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 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.

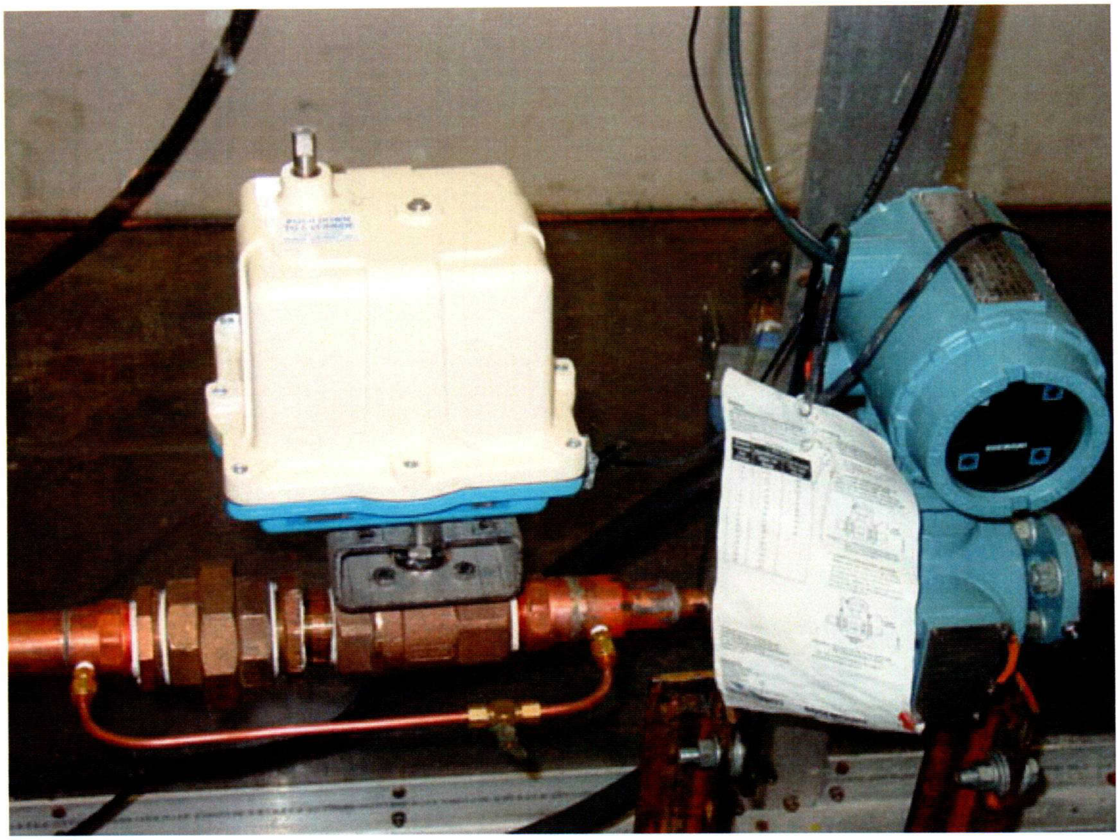


*Figure 5. **Electric motor actuated valve and bypass valve.***

IV. 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 SCRís, which in turn controls the electricity input to the rod bundle.

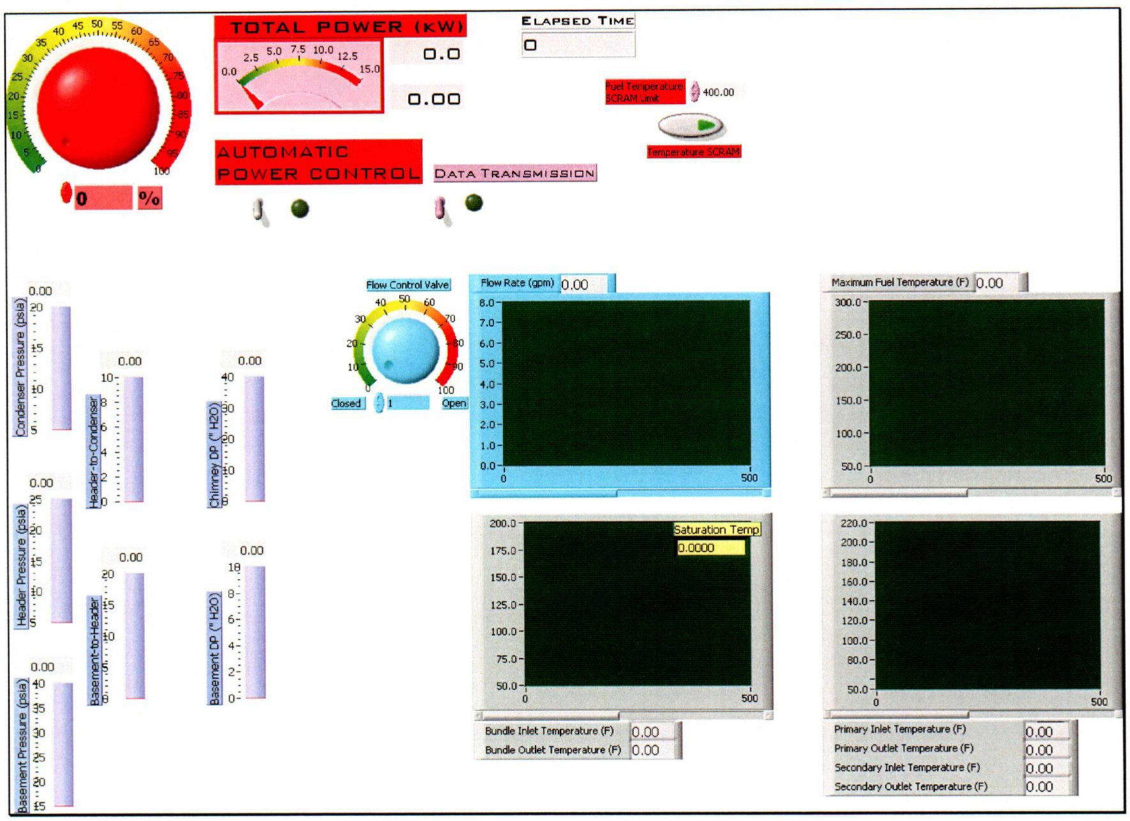


*Figure 6 – **Screenshot from the LabVIEW main control interface.***

V. 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.

IV.A. 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

C01

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.

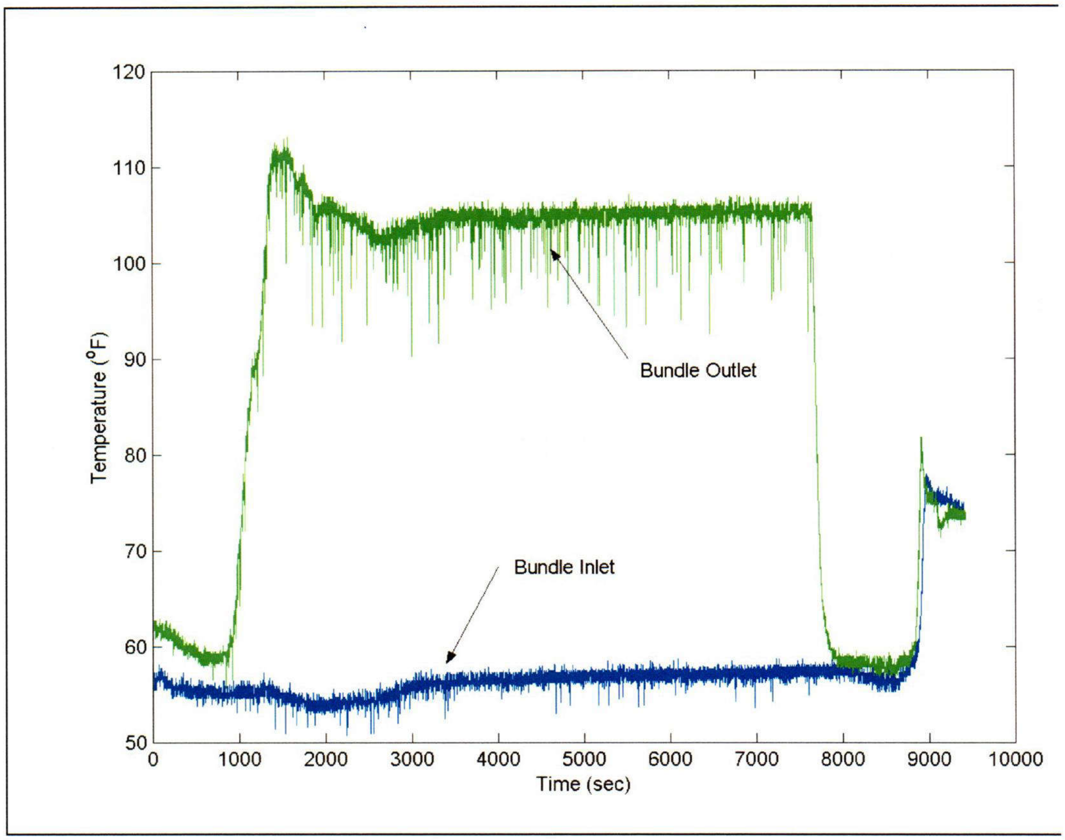


Figure 7 – History of the core mean temperatures during a single-phase flow.

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 heater rod axial temperature distribution is shown in Figure 10 for this experiment.

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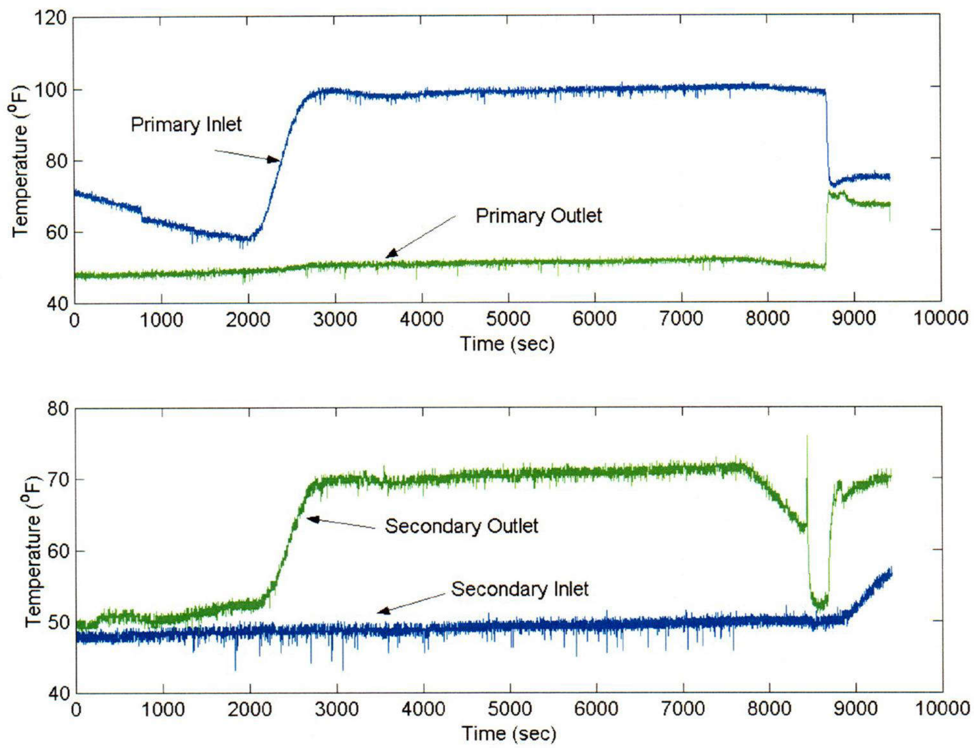

Figure 8 – ***Temperature history in the main condenser.***

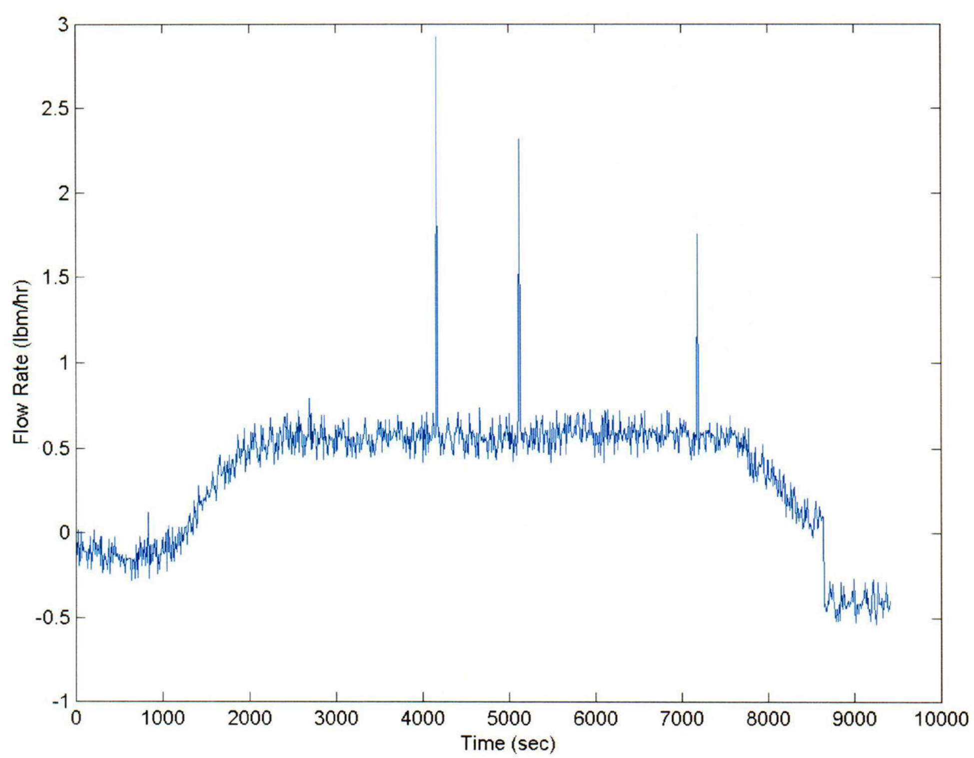

Figure 9 – ***Single-phase natural circulation flow rate.***

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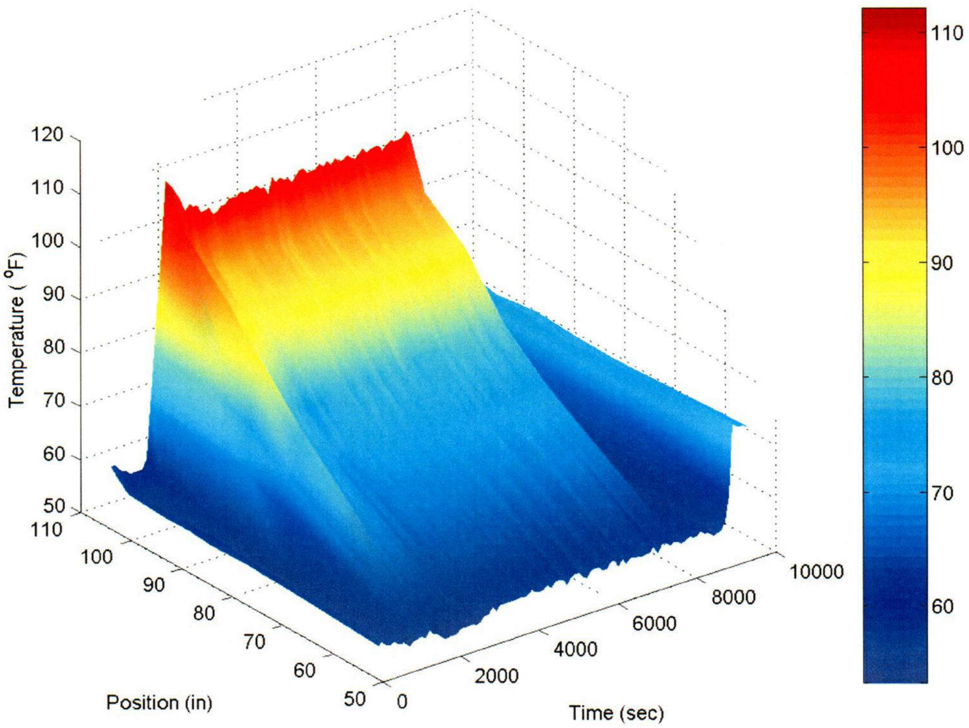

*Figure 1 – **3-D profile along the core of the fluid temperature for this particular experiment.***

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IV.B. 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.

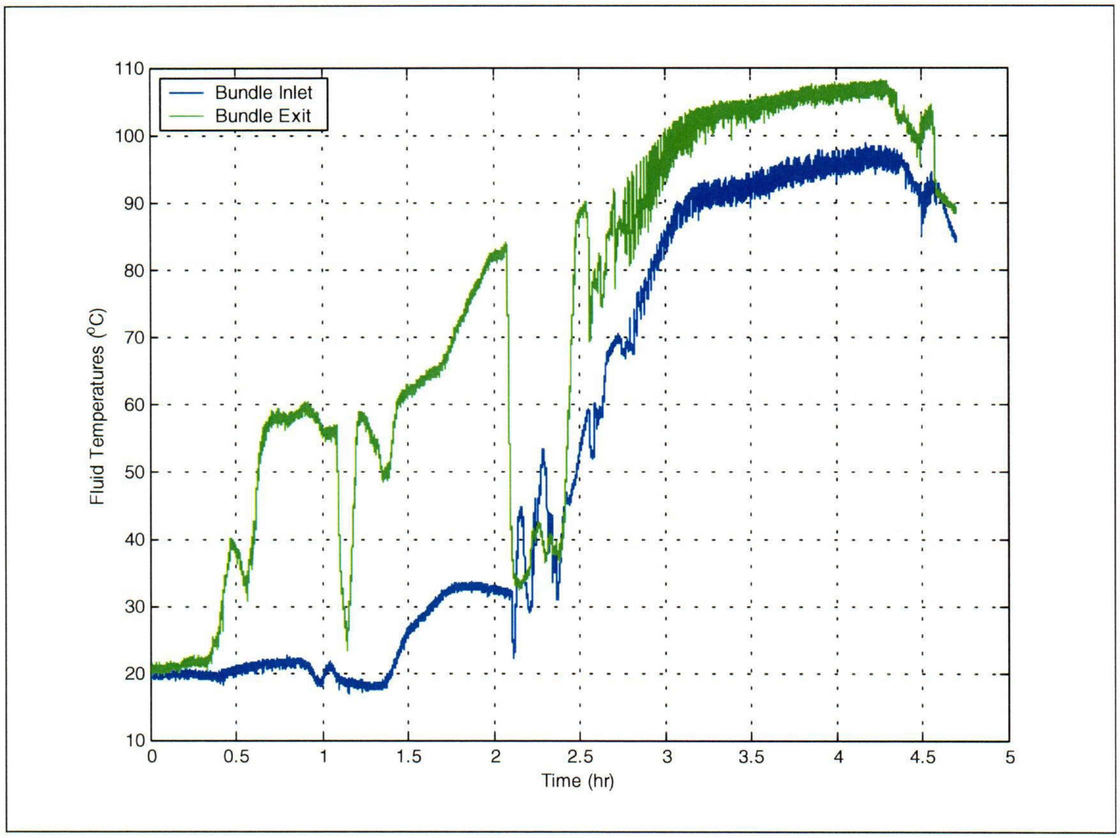

Figure 11 – Core fluid temperature history.

The two-phase natural circulation experiments are initiated as 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.

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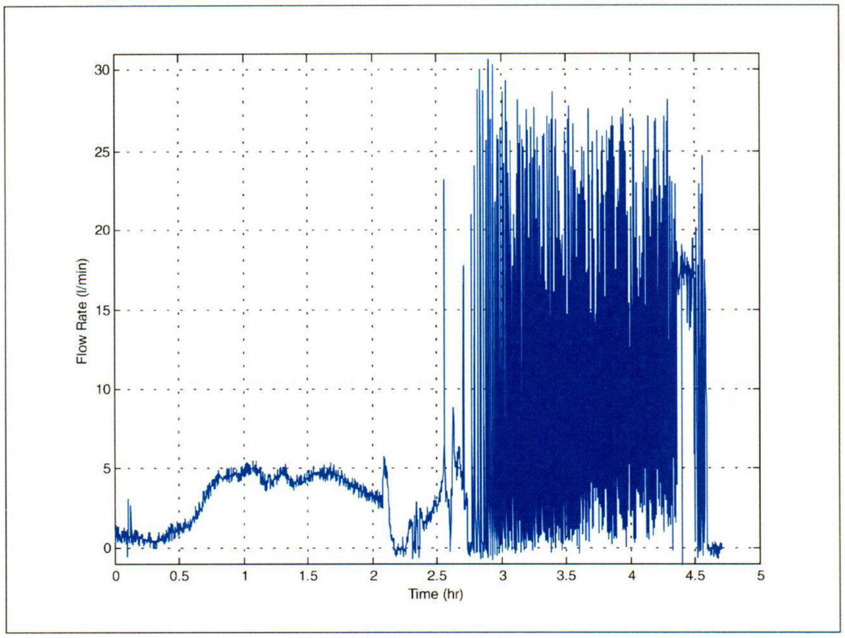

Figure 12 – ***Flow rate during the two-phase natural circulation experiment.***

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.

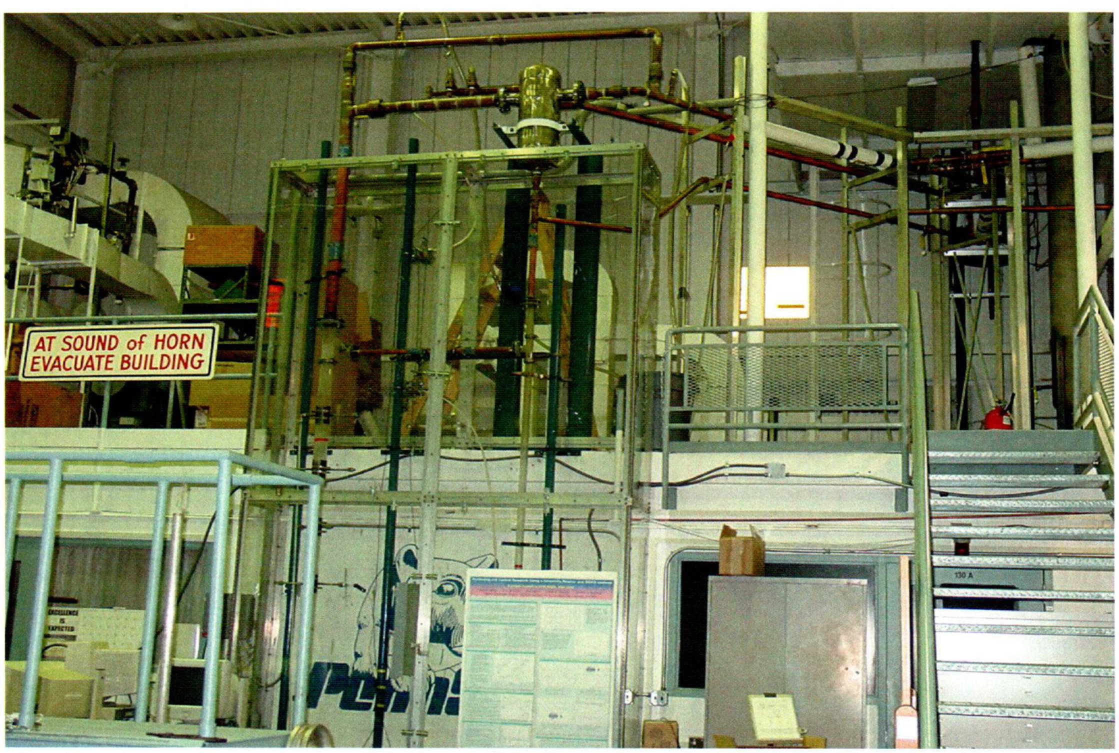

Figure 13 – ***The riser, chimney sections of the core; crossover leg, and steam separator.***

VI. 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 ìhands-onî 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.***

Environmental Health & Safety

X. ENVIRONMENTAL HEALTH AND SAFETY

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

The ALARA radiation protection philosophy, keeping the radiation exposure as low as reasonably achievable, is the basis for the RSEC 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

This year EHS performed more than 150 radiation surveys at the RSEC. Survey results showed that there were no radioactive contamination surveys or radiation surveys above the established limits. 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 attends 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.

Customer Service

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

Licensing and Regulatory Requirements

Requirements for dosimetery are administered by EHS to measure staff, student, and worker radiation exposures. This year the EHS issued a total of 561 dosimeters to RSEC personnel. Administration of the dosimeter program includes issuing dosimeters, processing dosimeters, and maintaining all dosimetery records. The RSEC's director is provided with quarterly dosimeter reports for his review. Out of the 561 dosimeters issued only one dose investigation was conducted. An investigation was conducted to determine the cause of a slight dose increase to the hands of reactor personnel analyzing samples in the neutron beam lab. It was found that the rack used to hold the samples was made of aluminum, which was becoming activated by the neutron beam. The situation was discussed with RSEC personnel and a new rack was designed out of material that would not become activated in the neutron beam. EHS will conduct follow up surveys to monitor the situation. Additionally, EHS provides on request, by signed permission only, dosimetry reports for reactor personnel and students so they can trace their exposure history. EHS provided fourteen dosimetry reports to other nuclear facilities in order for them to maintain the individual's exposure profile. EHS has administered a thermal neutron dosimeter program to check exposures more accurately for those working around the neutron radiography laboratory. One neutron dosimeter is a permanent fixture in the laboratory, and individuals wear the others as they work in the lab. A total of 168 thermal neutron dosimeters were monitored with no indication of any measurable thermal neutron exposures to personnel. Self-reading dosimeters are issued to transient persons and visitors to the RSEC. The information for the temporary dosimetry is documented in logbooks maintained by the administrative staff at the facility. EHS audits these exposure records to catch errors soon after they occur.

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

Additional Environmental Health and Safety support this year included the performance of four comprehensive lab safety inspections. No deficiencies were identified as a result of these inspections.

Training

Training programs provided by EHS to the RSEC are license and regulatory driven. This year, approximately 41 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. Training is also offered annually to cover chemical and chemical waste handling requirements. All new employees and students attended this mandatory training. Existing staff attended to meet the requirements for mandatory refresher training.

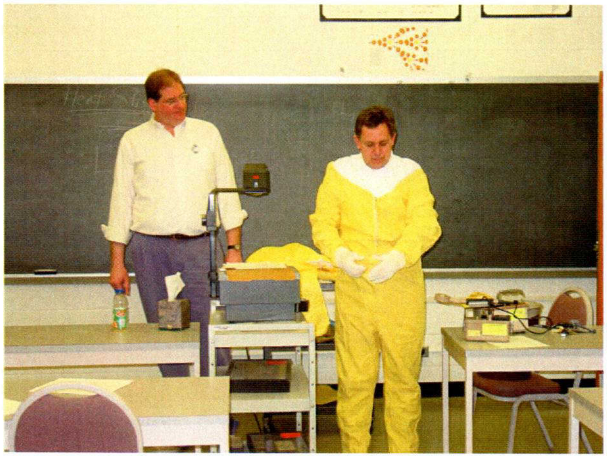

Figure 1. Mark Linsley (EHS) instructs while Thierry Daubenspeck volunteers during waste handling training.

Radiation Science & Engineering Center Research and Service Utilization

XI. RESEARCH AND 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 alphabetically by department in Section A. Theses, publications, papers, and technical presentations follow the research description to which they pertain. In addition, Section B lists users from industry and other universities.

The reporting of research and service information to the editor of this report is the option of the user, and therefore the projects in Sections A and B are only representative of the activities at the facility. The projects described involved 3 technical reports, presentations, or papers, 22 publications, 8 master's theses, and 2 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 users of RSEC facilities, including those listed in Sections A and B. Names of personnel are arranged under their department and college or under their company or other affiliation. During the past year, 63 faculty and staff members, 38 graduate students, and 15 undergraduate students have used the facility for research. This represents a usage by 18 departments or sections in 5 colleges of the University. In addition, 45 individuals from 24 industries, research organizations, or other universities used the RSEC facilities.

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

Agriculture and Biological Engineering Department

INACTIVATION OF *SALMONELLA* TYPHIMURIUM AND *E. COLI* O157:H7 ON PACKAGED MEAT DURING IRRADIATION

Participants: Ali Demirci, Asst. Prof.
Virendra M. Puri, Prof.
Catherine N. Cutter, Asst. Prof.
Kathirivan Krishnamurthy, Grad Student

Service Provided: Gamma Irradiation

Sponsor: Penn State College of Agricultural Sciences Seed Grant, $10,000

Various researchers have demonstrated that irradiation can greatly reduce food-borne pathogens, in some cases, completely eliminate the pathogens, while maintaining the quality of the food. Before irradiating the food products, they are packaged to avoid any cross-contamination after irradiation. The overall goal of this proposed study was to investigate the effect of packaging material in reducing irradiation doses.

Post-rigor beef samples were inoculated with approximately Escherichia coli O157:H7 or Salmonella Typhimurium and vacuum packaged with five different packaging materials (polyethylene, polypropylene, polynylon, low density polyethylene (LDPE), and polylactic acid (PLA)). The packaged beef samples were subjected to various irradiation doses (0.5, 1.0, and 2.0 kGy) in a Cobalt-60 irradiator. The irradiated meats were analyzed for microbial reduction, immediately after irradiation and after seven days of refrigerated storage at 4°C. The mechanical strength of packaging material and percentage elongation at break also were determined using an INSTRON machine.

The effect of packaging material, storage, and irradiation doses were significant for reducing populations of both E. coli O157:H7 and S. Typhimurium ($p<0.05$). Also, there was a significant interaction between plastic irradiation dose, irradiation dose storage, and plastic storage for samples inoculated with S. Typhimurium ($p<0.05$). However, for samples inoculated with E. coli O157:H7, only interaction between irradiation dose storage was significant ($p<0.05$). In general, E. coli O157:H7 exhibited a higher $\log_{10}$ CFU/cm^2 reduction than S. Typhimurium for all plastics. The range of D-values for E. coli O157:H7 and S. Typhimurium were 0.28 to 0.44 kGy and 0.32 to 2.17 kGy, respectively, for different packaging materials and storage condition. Generally, treatments following seven days of refrigerated storage exhibited higher $\log_{10}$ CFU/cm^2 reduction. Irradiation dose at 2.0 kGy demonstrated higher $\log_{10}$ CFU/cm^2 reduction than 0.5 kGy and 1.0 kGy. For E. coli O157:H7, LDPE exhibited higher CFU/cm^2 reduction. Treatments with PLA demonstrated a higher $\log_{10}$ reduction of S. Typhimurium. Mechanical properties, such as tensile strength and percentage elongation, were not changed significantly during irradiation and after seven days of refrigerated storage ($p>0.05$).

Master's Thesis:
Krishnamurthy, K., A. Demirci (Co-adviser) and V.M. Puri (Co-adviser). Inactivation of *Salmonella* Typhimurium and *E. coli* O157:H7 on packaged meat during irradiation, 2002.

Publications:
Krishnamurthy, K., A. Demirci, V. M. Puri, and C. N. Cutter. Effect of Packaging Materials on Pathogen Inactivation During Meat Irradiation. Northeast Agricultural and Biological Engineering Conference. Paper No. 02-006, June 2002.

Anthropology Department

PREHISTORIC METARHYOLITE USE AND MIGRATION IN THE MID-ATLANTIC REGION

Participants: K. Hirth, Professor
G. Bondar, PhD Candidate
C. Donaldson, UG

Services Provided: Neutron Irradiation, Radiation Counters, and Laboratory Space

Four thousand years ago, the Native American cultural continuum of the Mid-Atlantic and Northeastern regions of what is now the United States was apparently interrupted by the introduction of new and unique cultural practices. One diagnostic indicator of this discontinuity in the archaeological record across this region is the appearance of distinctive stone tools, popularly called "broadspears", which were often produced from an uncommon lithic material called metarhyolite. By using neutron activation analysis at

Penn State's Breazeale Nuclear Reactor facility, we intend to chemically characterize (or "fingerprint") geologic sources of metarhyolite to match broadspear-related artifacts to their sources of raw material. This unprecedented research, combined with several other quantitative measurements of the artifacts, should help determine whether the distribution of this cultural material from Georgia to New England is due to a prehistoric migration of people, a transfer of cultural traits, or an *in situ* response to environmental perturbations occurring at the end of the third millennium, B.C.

The analyses of the last year, greatly aided by the valuable efforts and contributions of Christopher Donaldson, an undergraduate student in Penn State's Department of Anthropology, has seen a doubling of the number of samples in the source database (Figs. 1 and 2). Not only has the number of samples from metarhyolite quarries in Pennsylvania achieved statistically-relevant size, but the addition of thirteen new sources, and the bolstering of several others analyzed previously, has made this research a tool of potentially inestimable importance to archaeology in eastern North America. Never before has quantifiable data existed that enabled the synthesis of models from across this vast and archaeologically-diverse region. The final year of this project will consist of the continued addition of source material to the database, both from new sources as well as those tested previously. To these, broadspear-related material from archaeological sites throughout the Mid-Atlantic and southern New England will be analyzed and assigned to contribute to our understanding of broadspear dispersal.

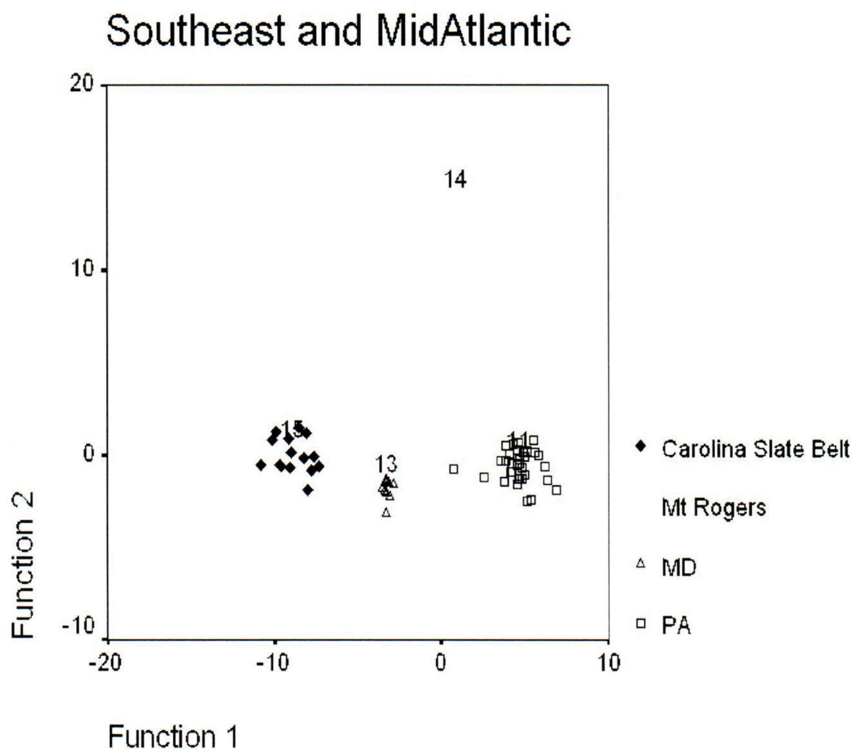

Figure 1: Compositions of metarhyolite from PA, MD, VA, and NC distinguished using discriminant analysis.

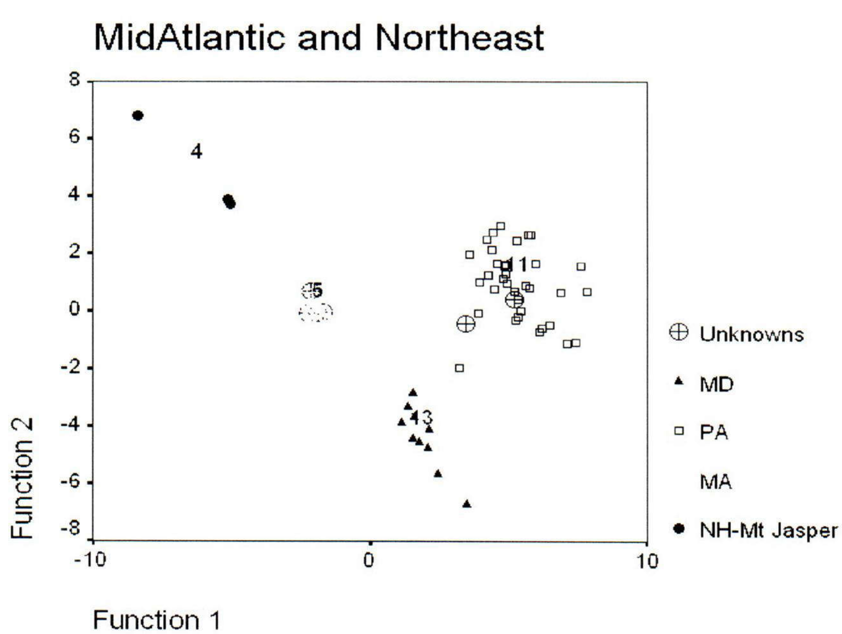

Figure 2: Compositions of metarhyolite from PA, MD, MA, and NH, including five artifacts, distinguished using discriminant analysis.

Doctoral Thesis:

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

Publication:

Bondar, G. H., C. E. Donaldson, and T. H. Daubenspeck. Characterization and Sourcing of Metarhyolite in the Northeast. Paper to be presented at the 69th Annual Meeting of the Eastern States Archaeological Federation in Mt. Laurel, New Jersey, 2002. (in preparation)

Biology Department

MISEXPRESSION OF BETAH CAUSES CELL DEATH

Participants: B. MacIver, Postdoc
G. Thomas, Assoc. Prof.

Services Provided: Gamma Irradiation

Sponsor: NIH

Hypothesis -- the protein string would suppress radiation induced cell death. No result. Project ceased.

Horticulture Department

INTERACTION BETWEEN SAPROTROPIC MICROBES AND ECTOMYCORRHIZAL FUNGI IN THE NITROGEN NUTRITION OF RED PINE

Participants: R. Koide, Prof.
T. Wu, Grad Student

Services Provided: GammaCell 220

Ectomycorrhizal (ECM) fungi can obtain nitrogen (N) from free protein under laboratory conditions. However, most of the protein in a forest is bound into a polyphenolic complex. ECM fungi cannot get N from polyphenol-protein complex. So we hypothesize that saprotrophic microorganisms in forest soils play an important role for ECM fungi in obtaining N from polyphenol-protein complex.

To test this hypothesis, we use γ - irradiated substrates (vermiculate + perlite) to grow ECM or non-ECM red pine seedlings with or without saprotrophic microorganisms which has or has no ability to mobilized N from the complex. We added tannic acids and protein to obtain a protein-tannin complex. We predict that there will be a significant interaction between saprotrophic organisms and ECM for the N nutrition of red pine seedlings.

However, we did not get the results we expected possibly due to the improper saprotrophic microorganisms we used. We are now repeating the experiments by using the F-layer as saprotrophic organisms. We anticipated that we will obtain the results before the end of this year (November, 2002).

Ph.D. Thesis:

Wu, T. and R. Koide (advisor). Interaction Between Saprotropic Microbes and Ectomycorrhizal Fungi in the Nitrogen Nutrition of Red Pine (in progress).

Material Science and Engineering Department

MEASUREMENT OF RESIDUAL ALUMINUM IN POLYMERS

Participants: I. Harrison, Prof.
S. Montgomery, Grad Student

Services Provided: Neutron Irradiation

The experiments used the nuclear reactor and neutron activation analysis to determine the amount of residual catalyst in several polymer samples. The polymer is a polyketone material that is synthesized through the use of an aluminum-based catalyst (aluminum chloride). Several washing methods were carried out on polymer samples to attempt to remove the catalyst. Through the use of neutron activation, the amount of residual aluminum in the polymer was measured in ppm's.

Mechanical and Nuclear Engineering Department

MONITORING AND CONTROL RESEARCH USING A UNIVERSITY RESEARCH REACTOR (PHASE III)

Participants: R.M. Edwards, Professor
S. Cetiner, Graduate Assistant
W. He, Graduate Assistant
Z. Huang, Graduate Assistant

Services Provided: Laboratory Space,
Machine Shop, Electronic Shop

Sponsor: DOE, $393,512 from 1999-2003

SUMMARY:

The 1999 DOE NEER-funded project on "Monitoring and Control Research Using a University Reactor and SBWR Test-Loop" has completed its Phase 3 goals and work is ongoing on the final phase. Phase 4 is scheduled to complete the 3-year project on June 30, 2002. Completion of the Phase 3 goals are discussed below.

Phase 3 was originally planned for the six-month period from January 1 to June 30, 2001. The first Phase 3 goal was to expand a Hybrid Loop Simulation (HLS) to incorporate modal kinetics and parallel boiling channel simulation. Completion of this goal was delayed and completed in October. The HLS uses an experimental low-pressure thermal hydraulic testloop that required repairs, instrumentation upgrades, and procedure development that could not be adequately anticipated and incorporated in the original work scope. The HLS was made sufficiently operational to complete Phase 3; however, additional repairs may be needed to fully accomplish all the Phase 4 goals. Specifically, the electrically heated rod-bundle currently operates at half the facility's design capacity and significant resources are needed to restore its full capacity.

The overall system layout is depicted in Fig. 1. All the state measurements from the Low-pressure Integral Test Facility (LPITF) are collected and processed in the host computer. This computer can also be used to control power input to the heater rods. The Monitoring and Control Interface relays some system state measurements, such as void, differential pressure, and temperature to the target computer. The Target Computer Control Interface relays simulated control rod reactivity (ρ_r) and void reactivity feedback gains (K_0 , K_1) to the target computer. The target computer in turn returns fundamental mode power (n_{0r}) to the host computer, which in turn can apply the signal to change the power of the electrically heated rods in the LPITF.

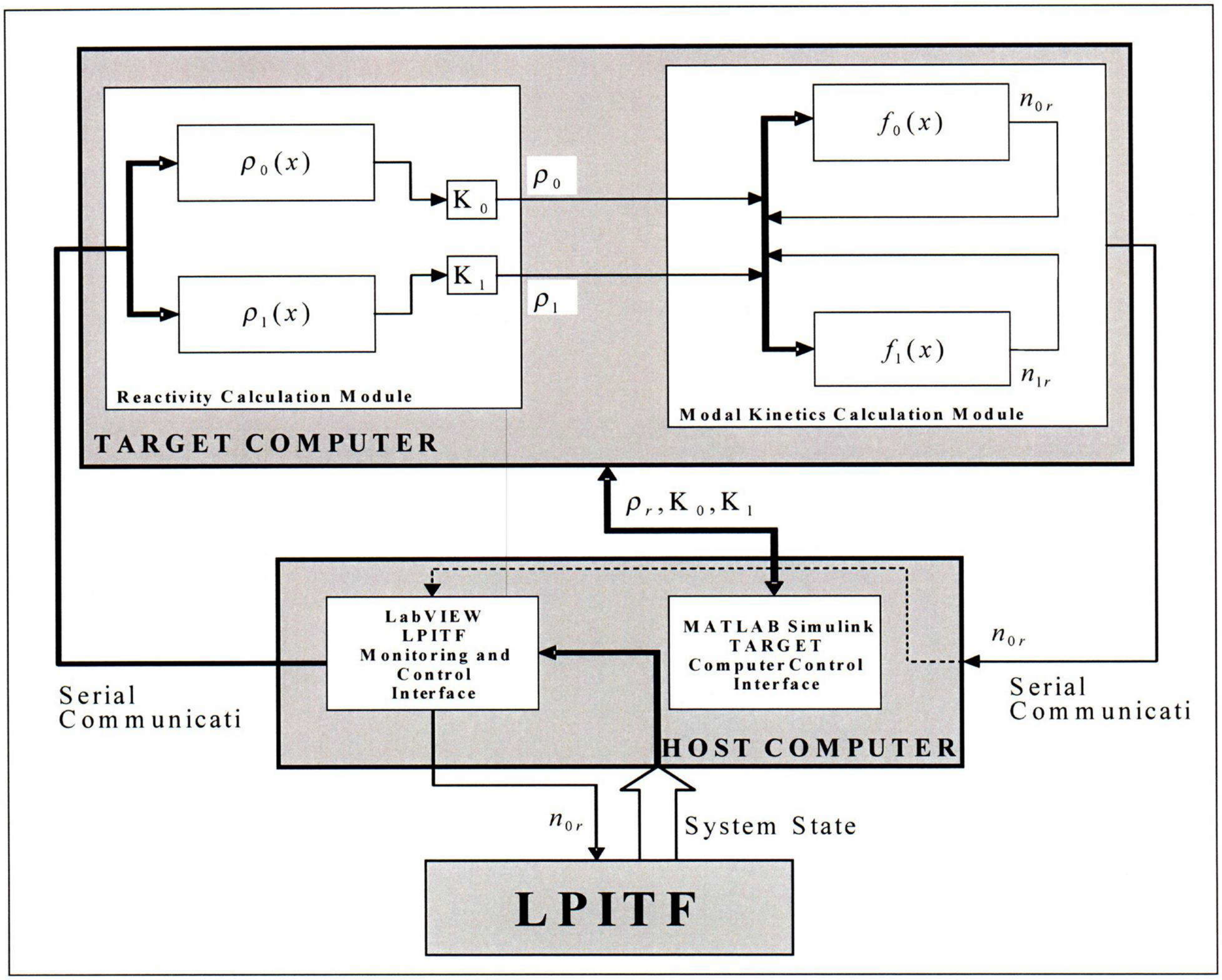

Fig. 1. The general structure of the hybrid loop simulator.

DISCUSSION:

Two goals were defined for Phase 3, and their accomplishments are briefly discussed.

The target computer runs the real-time modal reactor simulation application. The communication between the two computers is carried out via internet and serial line. Over the serial line is transmitted the status of the system and the feedback response streams over the same line. Serial communication speed is adequate compared to the system sampling period.

More details on the LPITF, the host computer and the target computer are presented in the following sections.

Low-Pressure Integral Test Facility (LPITF)

The LPITF is a half-scaled version of General Electric's Simplified Boiling Water Reactor (SBWR) operating at near atmospheric pressure (Fig. 2).

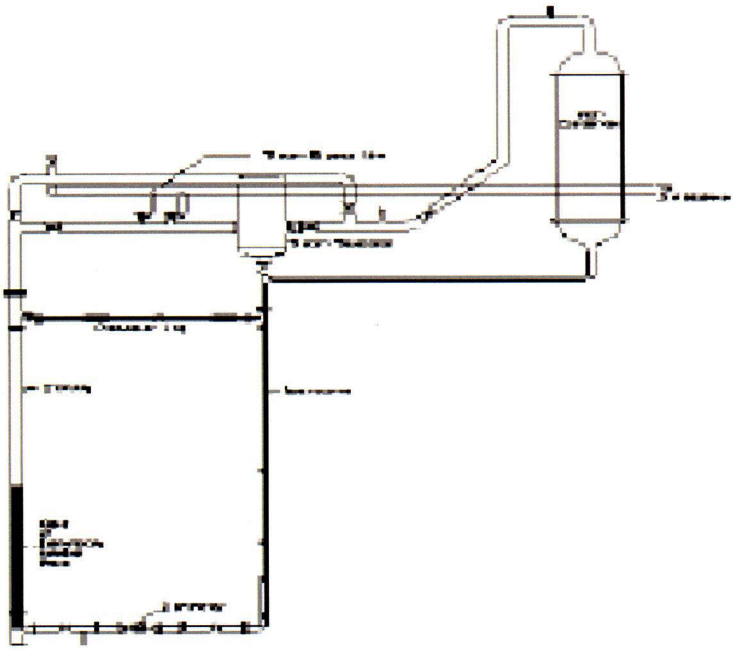

Fig. 2. Simplified drawing of the Penn State Low-Pressure Integral Test Facility.

In addition to the modeling of the reactor core, chimney and downcomer, the test loop also models the emergency core cooling systems (ECCS), gravity driven cooling system (GDCS), and isolation condenser (IC) (IC and GDCS are not used in this work and not shown in Fig. 2. The core, chimney and downcomer flows are made visible through borosilicate glass piping. The system is powered by electrically heated rods. The power is supplied over three silicon controlled rectifiers (SCR). SCR's can be controlled from an external unit. The external power control signal is sent from the host computer.

The core of the loop is heated by 12 heater rods; a number calculated through Ishi's scaling law. The rods are manufactured in the same diameter as the SBWR assembly rods, allowing more realistic subchannel analysis. The water flow through the core is mixed by the use of BWR grid spacers.

The LPITF is installed with a number of instrumentation in order to capture the physical state of the system more accurately. Among the instrumentation are a very sensitive magnetic flowmeter for the primary circuit flow, pressure cells around the flow path, fluid and rod surface thermocouples, void probes, and power transducers.

Host Computer

Data monitoring and control interfaces have been implemented with National Instruments LabVIEW software. LabVIEW provides a very easy-to-use programming environment, which is fully based on graphical programming, as well as extensive graphical user interface and development tools. LabVIEW also has the capability to create a virtual interface for world-wide-web based experiments. Fig. 3 gives a screenshot from the main control diagram. Three plot screens provide visual aid for the three important system state variables. At the top on the right-hand side is a power control knob, which determines the power signal to be transmitted to SCR power control units. In this work, the SCRs are balanced so that the power applied to each SCR is the same.

Each SCR output is also connected to a power transducer to verify applied power. The signals read back through the transducers are made visible by the power meter display next to the power knob.

Below the power meter is located a thermometer display for the maximum rod temperature. Maximum rod temperature limit is one of the safety restrictions to ensure borosilicate glass integrity.

At the right of the screen are the two buttons: “Target Communication” and “Target Control”. With target communication on, the two computer systems read and send data from/to each other, but power control is still manual as long as target control is disabled.

If target control button is on, then the power level calculated at the target computer based on the neutronic model is applied to control the heater rods.

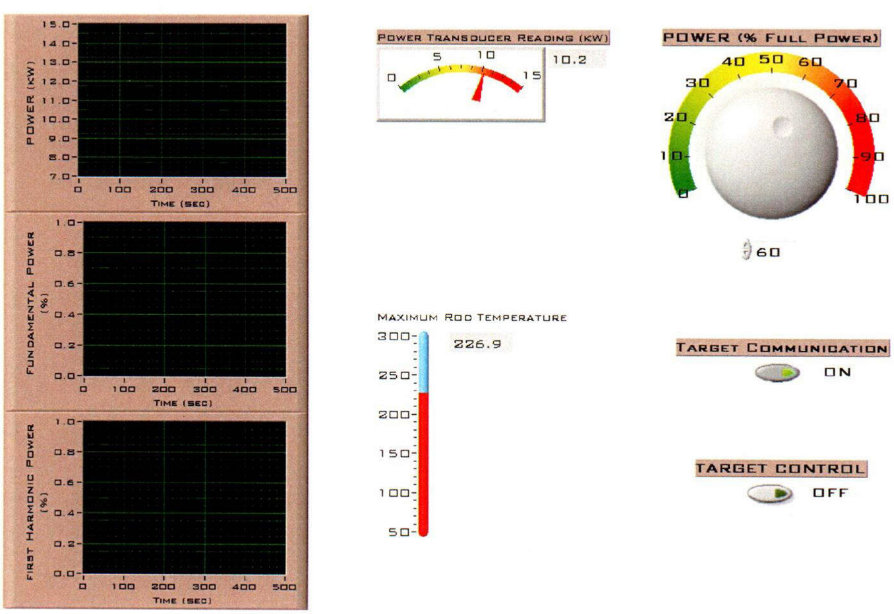

Fig. 3. Monitoring and control interface designed with LabVIEW 6i.

Target Computer

Target computer represented at the top of Fig. 1 reads measurements data from the host computer over a serial line. The data is processed in real-time and the calculational results are transmitted back to the host computer over the serial line again. The target computer provides real-time simulation of modal reactor kinetics (n_{0_r} , n_{1_r}) and a detailed boiling channel simulation for the out-of-phase mode reactivity feedback ($\rho_1(x)$). Void and other measurements from the LPITF are used to set fundamental mode reactivity feedback ($\rho_0(x)$). The magnitude of the modal kinetics reactivity feedback (ρ_0, ρ_1) are multiplied by adjustable gain parameters K_0 and K_1. The output from the target computer is the fundamental mode power to be applied to heater rods.

EXPERIMENTAL PROCEDURE AND RESULTS

Since the thermal-hydraulic test loop has borosilicate components, care has to be taken for the pressure limitations. In order to avoid over pressurization in the system, operation is carried out at near atmospheric pressure.

Fig. 4 presents the natural circulation driven coolant flow rate during startup and operation of the LPITF.

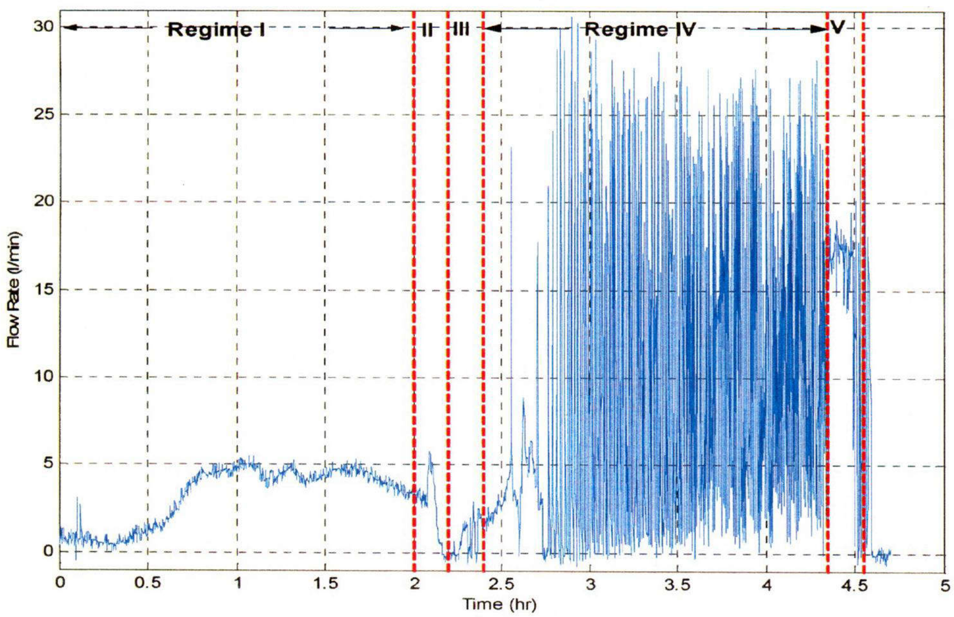

Fig. 4. Variation of flow rate throughout the entire test loop operation. The effect of system depressurization can be seen around 2nd hour. Regime I: single phase heating; Regime II: draining a portion of the system inventory; Regime III: system reheat; Regime IV: flow oscillations in two-phase region; Regime V: stable two-phase flow behavior.

The general steps through various regimes can be summarized as follows:

i. The loop is filled with water, and left open to the atmosphere to avoid pressurization; condenser secondary side flow is set to around 20 l/min in order to help initialize and develop natural circulation with a higher temperature gradient between the two ends of the system (Regime I).
ii. Once the average core temperature approaches 90 °C, power to the rods is turned off; condenser secondary side flow is reduced to around 2 l/min so as to let the liquid inventory become more homogeneous in temperature.
iii. The system is closed to the atmosphere.
iv. A drain valve at the lowest point of the loop is opened to slowly reduce water inventory. As water inventory is reduced, the hot water flashes to steam to fill the volume created by the draining liquid. The pressure in the upper portions of the loop drops below atmospheric (Regime II and III).
v. Having drained the water to a desired level –usually just below the cross over leg (Fig. 2) – power to the rods is slowly increased and the system develops until steady two-phase natural circulation conditions are achieved. System pressure slowly increases owing to continued heat input.

Due to low system pressure and additional heating needed to establish a two-phase natural circulation flow path, the LPITF is unstable in Regime IV indicated in Fig. 4. The steady two-phase natural circulation regime develops after steam begins to reach the inlet to the condenser.

In Region V, steady two-phase flow, a recirculation flow path is established along the loop through the inlet of the core to chimney to crossover leg (behaves like upper plenum) to downcomer to lower plenum, and core inlet again. Steam flow through the separator, condenser, and liquid return to the downcomer is also established. Power is manually set to 65 % (of the facility's reduced capacity). The communication between the host computer and the target computer is commenced.

Simulated reactor kinetics on the target computer is controlled over the host computer via MATLAB Simulink interface through simulated rod reactivity (ρ_r), fundamental mode gain (K_0), and first harmonic mode gain (K_1). These parameters are adjusted properly to set the simulated power exactly to 65 % prior to connecting the output for fundamental mode power to the heater rods. The power control from LabVIEW is no longer active through its power knob.

DATA ANALYSIS

Fig. 5 plots the entire operation history for core fluid temperatures. The onset of the second stage of the operation, where system inventory is partially drained and then the bundle power is recovered, starts about 2.2 hr after the experiment is commenced. The system stabilizes around 4.3rd hour, about 2 hours after the second stage starts.

The power control is transferred to the target computer around 4.4th hour and the simulated reactor took over the control for about 5 minutes.

Fig. 6 through Fig. 8 present the coupled behavior of the hybrid system. These figures are five-minute details from the operation around 4.4th hour. Fig. 6 presents simulated rod reactivity (ρ_r), fundamental mode power (n_{0r}), and fundamental mode reactivity feedback gain (K_0).

Fig. 7 presents first harmonic mode power (n_{1r}) and first harmonic mode reactivity feedback gain (K_1). Fig. 8 presents fundamental mode reactivity (ρ_0) and first harmonic mode reactivity (ρ_1).

To help understand the response of the system, the hybrid experiment can be analyzed in three regions. Each region shows different characteristic behaviors: The first region is where the fundamental mode reactivity feedback gain (K_0) is kept zero and the system excitation is done through the first harmonic excitation by setting its feedback gain (K_1, Fig. 7) above the critical value (~ 10.65). In Region II, the first harmonic gain is set to a sub-critical value (< 10.65) and the primary interaction with the LPITF boiling channel is through the fundamental mode void reactivity (K_0, Fig. 6) and Doppler feedback. The Region III is basically the same as the Region II, and only differs in the first harmonic gain set back to its critical value.

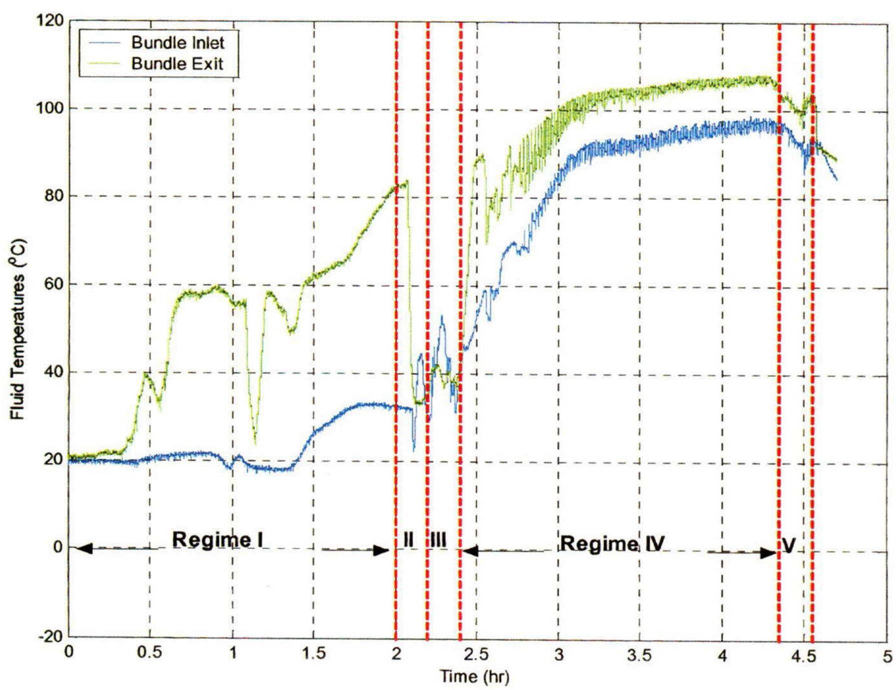

Fig. 5. The variation of average fluid temperatures at bundle inlet and bundle exit.

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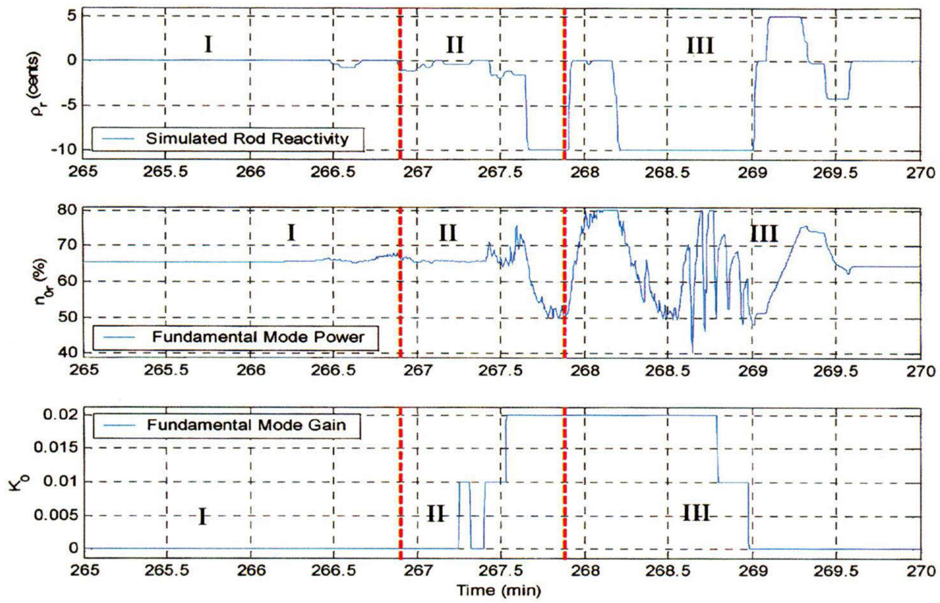

Fig. 6. Behavior fundamental mode during the hybrid experiment.

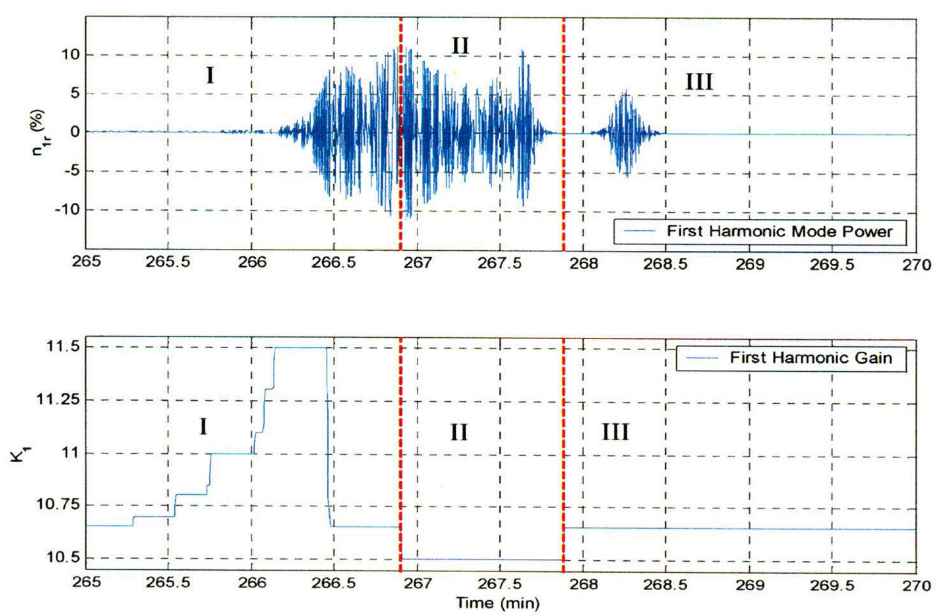

Fig. 7. Behavior of first harmonic mode.

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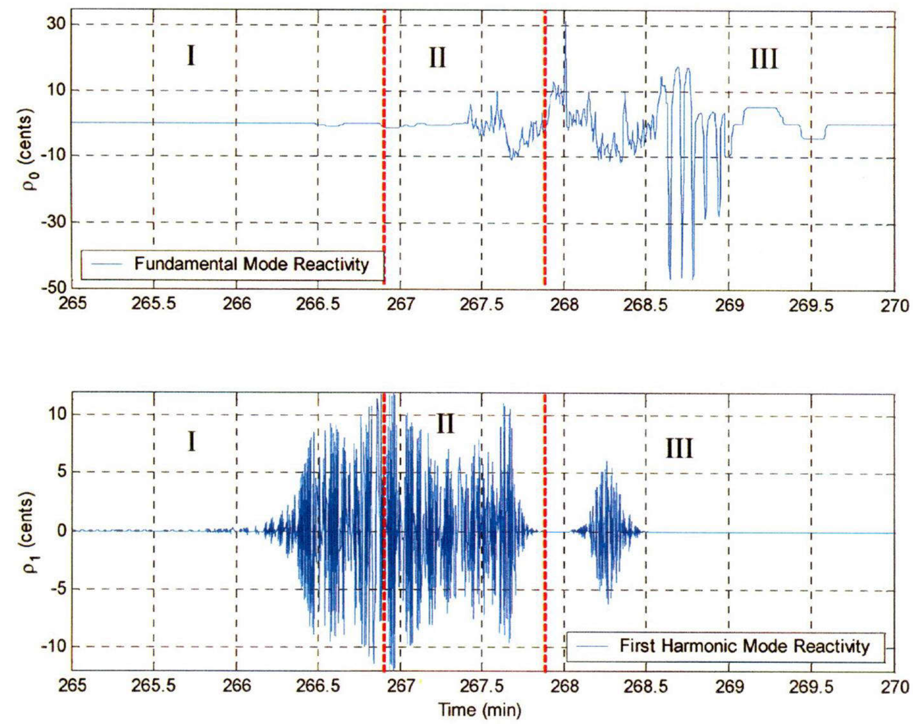

Fig. 8. Response of the reactor due to Doppler and void reactivity feedbacks in terms of fundamental and first harmonic reactivities.

Region I

As explained above, the response in the first region is dominated by the out-of-phase oscillations. The lower plot in Fig. 7 shows the first harmonic gain (K_1). The top plot in the same figure represents the first harmonic power and as can be seen, the out-of-phase oscillations become notable around the 266th minute.

An interesting characteristic of this region can be seen in Fig. 6, where simulated rod reactivity (ρ_r), fundamental mode power (n_{0r}), and void reactivity feedback gain (K_0) are plotted. The fundamental mode power starts to exhibit a small amplitude frequency component of about 1 Hz around 266.5th minute, even though the fundamental mode feedback gain is zero. The reason for this oscillation is the cross-mode excitation: The interaction of the fundamental mode with the first harmonic results in excitation in the global power. This is usually observed in real BWRís over the APRM (Average Power Range Monitors) and is an indication of the out-of-phase oscillations.

C09

The additional characteristics of the first region can also be seen in fundamental and first harmonic reactivities, ρ_0 and ρ_1, respectively, in Fig. 8. The excitation of the fundamental mode through the interaction with the first harmonic results in first harmonic reactivity oscillations, which in turn affects the global power.

Region II

The response of this region is dominated by the fundamental mode Doppler and void reactivity feedbacks. The gain of the first harmonic mode (K_1) is set to a below-critical value in order to begin to suppress the large out-of-phase oscillations that developed in Region I. The fundamental mode gain (K_0) is adjusted in order to avoid any sudden power changes. The fundamental mode power is also affected through the simulated rod reactivity insertions, as plotted in the top section in Fig. 6. In order to study the void reactivity feedback, power is changed through the simulated control rod, ρ_r. The response of the reactor to a step decrease in reactivity of 10 ¢ can also be seen in the same region. The fundamental mode power follows the simulated rod reactivity, but with smaller amplitude and higher frequency oscillatory components superimposed.

These high frequency oscillations result from the interaction with the first harmonic mode. In Region II in Fig. 7, the leftover oscillation after the first harmonic gain is decreased to below the critical value is still large enough to affect the fundamental mode power. As fundamental mode power drifts upward, it reinforces the oscillatory behavior of the first harmonic mode, much like increasing the first harmonic gain (K_1) while fundamental mode is steady. When rod reactivity is changed to -10 ¢, fundamental mode power decreases about 15% and the first harmonic oscillation is suppressed.

The contribution of the fundamental mode void reactivity feedback dominates at the end of Region II, because of the suppression of the first harmonic mode. Moreover, this fluctuation frequency is a signature of a different interaction. If pressure drop along the chimney is focused around this region, it's possible to see that these higher-frequency oscillations result from the changes in the void fraction. The spectrum of the fundamental mode power when $K_0 > 0$ has a frequency resonance at $\omega = 0.0161$ rad/sec $\cong 0.1$ Hz, a characteristic frequency for pressure-drop oscillations. Pressure drop oscillation is a double instability mode, in which Ledinegg-type instability and a compressible volume in a boiling system interact and produce a low-frequency oscillation.

The reason that those fluctuations did not appear before is that fundamental mode gain was zero. Setting it to a nonzero value carries the effect of void fluctuations to reactor kinetics and those effects are superimposed on fundamental mode power. At the beginning of Region III simulated control rod reactivity (ρ_r) is set back to zero and this results in about 15 % overshoot in the global power from the steady-state value.

Region III

Even though the Region III differs in the first harmonic mode gain set to its critical value from the region II, the genuine distinction is that the out-of-phase oscillations are re-excited after they all die away. As can be seen in the top section of the Fig. 7, the first harmonic power dies away around 268^{th} minute. The first harmonic gain is then set back to its critical value and kept the same. However, the large amplitude of the global power succeeds to enliven the first harmonic oscillations albeit the first harmonic gain is critical.

As the power goes down after a 10-cent reactivity insertion around 267.7^{th} minute for relatively long time the cross-mode interaction does not appear as effective as before. The big-amplitude, low-frequency oscillations between 268.5 and 269^{th} minutes do not have high-frequency components because the first harmonic power died away. Since the power level is comparatively low, cross-mode excitation does not take place effectively as it did before despite the first harmonic gain is still critical.

Once the loop becomes unstable, the power control is handed back over to the host computer, and the system is shut down and secured

THE SECOND GOAL OF PHASE 3

Task 8 in the 3-year project was to evaluate in-phase and out-of-phase BWR stability. The in-phase oscillation is associated with the fundamental mode of neutron distribution. When in-phase oscillations occur, the local power change is consistent with the average power change. The out-of-phase instability is associated with the first harmonic mode of neutron distribution. In an out-of-phase event, the average power level may not fluctuate noticeably while half of the core oscillates out-of-phase of the other half . This report is a summary of the work in developing and testing two types of stability monitors for the in-phase and out-of-phase instability events.

1. In-Phase Stability Monitor

The first experiment was to evaluate an in-phase stability monitor. The setup is illustrated schematically in Fig. 9. In the setup, the real-time simulation of the thermal hydraulic phenomena in a boiling water reactor channel is coupled with the Penn TRIGA reactor forming a hybrid BWR reactor system. The measured reactor power signal drives the thermal hydraulic channel model, which computes the void reactivity feedback. The void reactivity feedback is realized by using the Experimental Changeable Reactivity Device (ECRD) to drive the TRIGA reactor. The Adjustable Gain Block is included for two purposes. First, it is used to introduce perturbation into the close loop system. Second, it is used to compensate for the ECRD dynamics, which is not inherent in the BWR dynamics. In our work, the hybrid BWR system is used as a test-bed to evaluate the BWR stability monitors. The stability monitor is an extended Kalman filter, which is based on a simplified linear thermal hydraulic model coupled with one-group nonlinear point kinetics model. Based on the measured reactor power and external reactivity input (set to zero in our tests), the filter makes real-time estimations of the feedback gain, decay ratio and oscillation frequency of the closed-loop system.

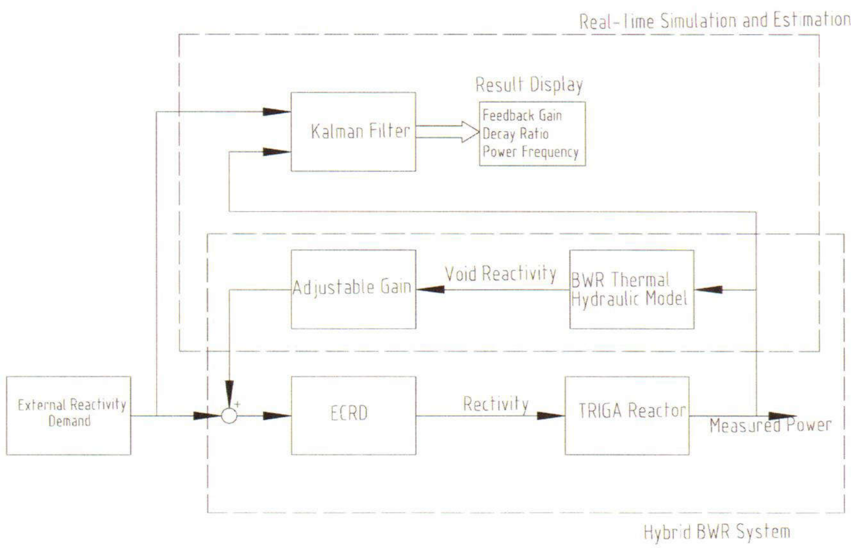

Fig. 9: Setup for Testing the Core-Wide Stability Monitor

Some test results are presented in Fig. 10. In the experiment, before the void feedback was introduced, the ECRD was properly positioned and the reactor was maintained at a steady operation level with the main control rod system of the TRIGA reactor. The void feedback loop was closed at about 20 seconds. From top to bottom, the figure gives the history of the adjustable gain change, measured reactor power, the estimated feedback gain, closed-loop decay ratio and corresponding frequency. The estimated decay ratio gives a direct indication how far the system is from its stable condition. From the figure, the estimated decay ratio was close to 1.0 except during some transition periods. The estimated decay ratio is confirmed by the measured reactor power, which shows that the BWR hybrid system was approaching limit cycle. The transitions in the estimation are caused by the dynamic behavior of the Kalman filter. The estimated frequency is close to 0.5 Hz, which is close to the value obtained directly according to the measured reactor power.

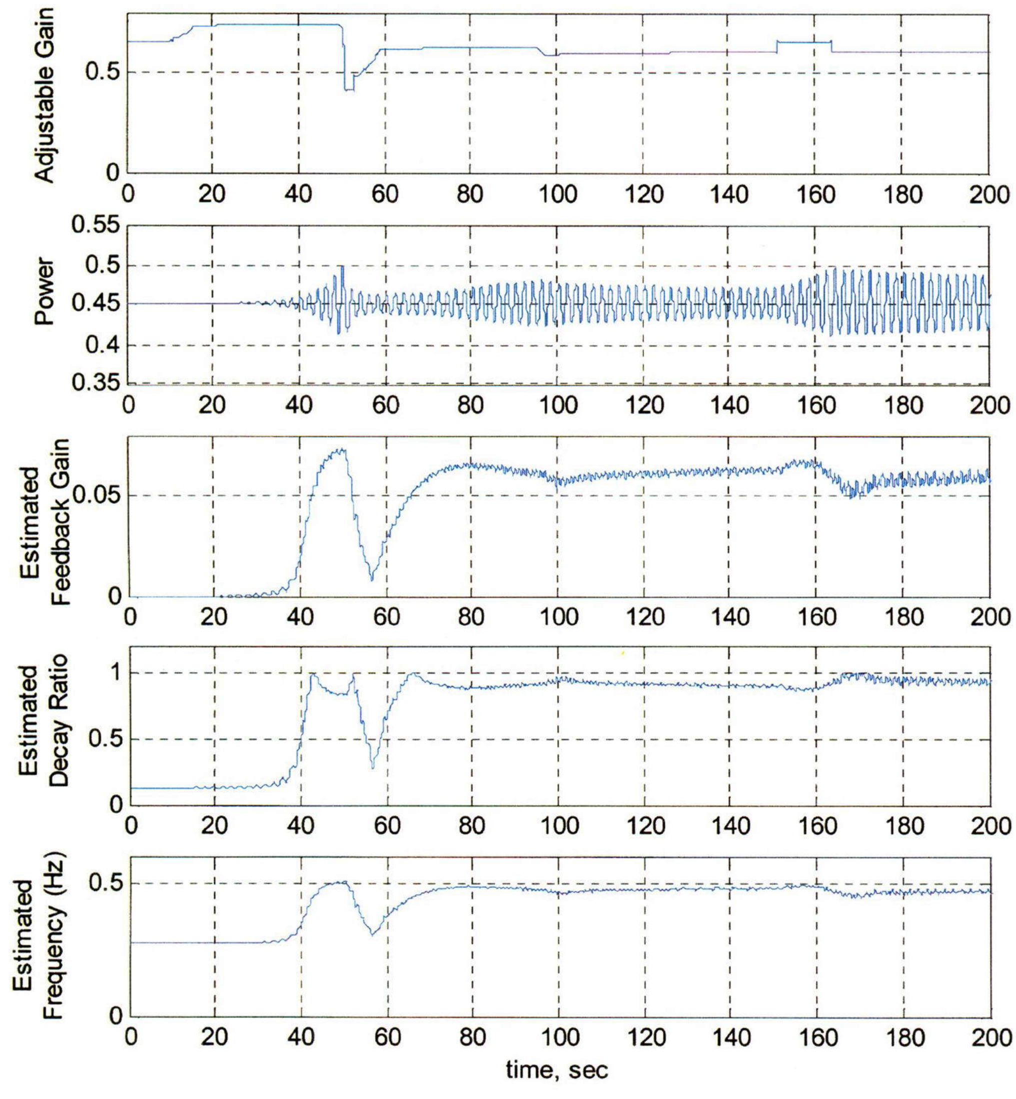

Fig. 10: Results for In-Phase Stability Monitoring Experiments

Further work should be focused on two aspects. First, the above analysis shows that the estimator did not follow the plant very well when the plant experienced a fast transient. The Kalman filter design could be improved to get better performance. Secondly, the dynamics of the ECRD could be better determined so that its dynamics can be accounted for in the hybrid simulation and/or the stability monitor.

2. Out-of-Phase Stability Monitor

The experimental setup for the implementation and testing of the out-of-phase stability monitor is schematically illustrated in Fig. 11. The TRIGA reactor and the simulated first harmonic kinetics are used to approximate modal neutron kinetics. The thermal-hydraulic block consists of two boiling channels. One channel represents the fundamental mode and the other represents the harmonic mode. Each channel contributes to the system stability through its void reactivity feedback, and the channels interact through the two coupling modes of the neutron kinetics. Two Kalman filters are used respectively as instability monitors for the two types of instability events. The Kalman filters give the real-time estimation of the decay ratios, frequencies and void feedback gains for each mode.

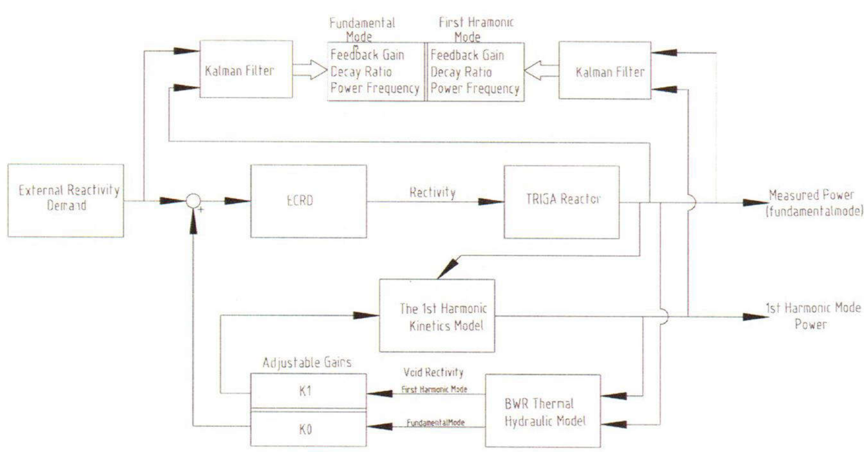

Fig. 11: Setup for Testing In-Phase and Out-of-Phase Stability Monitors

Some experimental results are plotted in Fig. 12. On the left are the results from the fundamental mode monitor. The results from the monitor for the first harmonic mode are shown on the right. According to the measured TRIGA power and the simulated output of the 1st harmonic component, the filters give reasonable estimation of decay ratios and oscillation frequencies when the estimations converge. It also shows that the filter for the 1st harmonic mode monitor shows a better response compared to the filter for the fundamental mode monitor. The fundamental mode monitor shows poor performance in following the plant and needs to be improved in the future work.

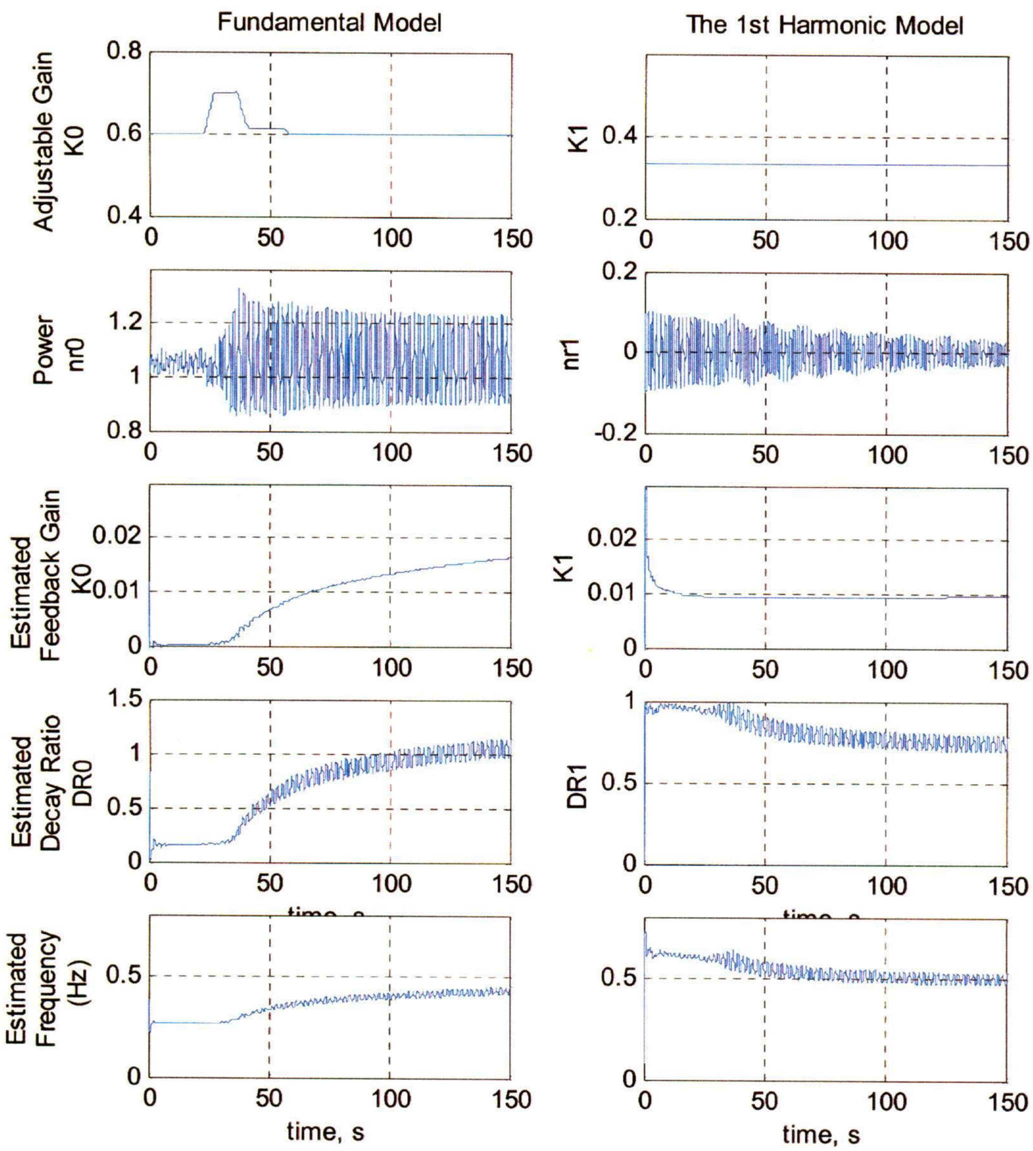

Fig. 12: Results for Out-Phase Stability Monitoring Experiment

CONCLUSION:

The 1999 DOE NEER-funded project on "Monitoring and Control Research Using a University Reactor and SBWR Test-Loop" has completed all of its Phase 1, 2, and 3 goals and is currently proceeding in the final phase. Phase 4, and the project, is scheduled for completion on June 30, 2002. The Phase 4 goals are a) implement hybrid reactor testloop simulator capability with optional modal kinetics and parallel boiling channel simulations, b) design and implement flow control for the SBWR test-loop, c) develop wide-range automated control for BWR incorporating optimized feedforward and robust feedback control (completed), and d) evaluate wide range ABWR control in the hybrid simulation environment.

Theses:

1. Roman Shaffer, "Design, Simulation, and Validation of Robust Controllers", a Masters Thesis in Nuclear Engineering, The Pennsylvania Stat University, May 2000.

2. Shian-shing Shyu, "A Robust Multivariable Feedforward/Feedback Controller Design for Integrated Power Control of Nuclear Power Plant", A Dissertation in Nuclear Engineering, The Pennsylvania State University, May 2001.

3. Zhengyu Huang, "Fuzzy Logic Controller Design for Overall Control of a Nuclear Power Plant", A Masters Thesis in Electrical Engineering, The Pennsylvania State University, August 2001.

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4. Huang, Z., and R.M. Edwards. 2001. Simulation of BWR Out-of-Phase Oscillation Using a University Research Reactor. Trans. of the Amer. Nucl. Soc. Student Conference. College Station, TX. 7 pages on CD ROM.

5. He, W., and R.M. Edwards. 2001. Robust Design an Evaluation of On-line Uncertainty Monitoring System on a Reactor . Trans. of the Amer. Nucl. Soc. Student Conference. College Station, TX. 6 pages on CD ROM.

6. Cetiner, M., and R.M. Edwards. 2001. The Pennsylvania State University Low Pressure Integral Test Facility Data Acquisition System and User Interface. Trans. of the Amer. Nucl. Soc. Student Conference. College Station, TX. 7 pages on CD ROM.

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12. Ceceñas-Falcón, M., and R.M. Edwards. Out-of-Phase BWR Stability Monitoring. Submitted September 2001 for publication in Nuclear Technology.

13. Huang, Z., and R.M. Edwards. Hybrid Reactor Simulation of BWR Power Oscillations. Submitted October 2001 for publication in Nuclear Technology.

14. Shyu, S., and R.M. Edwards. A Robust Multivariable Feedforward/Feedback Controller Design for an Integrated Power Control of Nuclear Power Plant. Submitted November 2001 for publication in Nuclear Technology.

15. Shaffer, R., W. He, and R.M. Edwards. Design And Validation Of Optimized Feedforward With Robust Feedback Control of A Nuclear Reactor. Submitted December 2001 for publication in Nuclear Technology.

16. He, W., and R.M. Edwards. Evaluation of in-phase and out-phase BWR Stability Monitors. Submitted January 2002 for publication in Transactions of The American Nuclear Society.. (First author supervised by candidate)

17. Huang, Z., and R.M. Edwards. ABWR Plant Overall Control Using Fuzzy Logic Control Technique. Submitted January 2002 for publication in Transactions of The American Nuclear Society.

18. Cetiner, S.M., and R.M. Edwards. Integration of a Thermal-Hydraulic Test Loop and University Research Reactor For Advanced Control. Submitted January 2002 for publication in Transactions of The American Nuclear Society.

19. He, W., Z. Huang, and R.M. Edwards. Advanced BWR Stability Monitoring Tests with a Hybrid Reactor Facility. Submitted 400-word abstract January 2002 for full paper that would be due April 1, 2002 for publication in Proceedings of American Nuclear Society Topical Meeting, International Congress on Advanced Nuclear Power Plants (ICAPP).

20. Huang, Z., and R.M. Edwards. Sliding Mode Control Application in ABWR Plant Pressure Regulation. Submitted 400-word abstract January 2002 for full paper that would be due April 1, 2002 for publication in Proceedings of American Nuclear Society Topical Meeting, International Congress on Advanced Nuclear Power Plants (ICAPP).

21. Cetiner, S.M., and R.M. Edwards. Results of Coupling a Thermal-Hydraulic Test Loop and University Research Reactor. Submitted 400-word abstract January 2002 for full paper that would be due April 1, 2002 for publication in Proceedings of American Nuclear Society Topical Meeting, International Congress on Advanced Nuclear Power Plants (ICAPP).

THERMAL-HYDRAULIC BEHAVIOR OF THE PENN STATE BREAZEALE NUCLEAR REACTOR (PSBR)

Participants: J.E. Chang, Research Assistant
L.E. Hochreiter, Prof.
T.F. Miller, Research Associate

Services Provided: Reactor Pool

Sponsor: Radiation Science and Engineering Center, PSU

INTRODUCTION

Earlier experiments determined that the Pennsylvania State University Breazeale Nuclear Reactor (PSBR) is cooled, not by an axial flow, but rather by a strong cross-flow that is induced into the core by natural circulation caused by density differences due to the heating of the pool water. Later, there was a nitrogen-16 (N-16) pump installed at the top of the core in order to prevent the rapid release of radioactive N-16. The interaction between the N-16 jet flow and buoyancy induced flow makes it complicated to analyze the flow distribution in the PSBR pool.

The objective of this project is to develop an improved method of characterizing the thermal-hydraulic behavior of the PSBR. The work is to determine the flow distribution in and around the reactor core such that once the flow field was known, the temperature response of the fuel rods could be determined and explained. The program includes developing a Computational Fluid Dynamics (CFD) model for the PSBR flow and temperature distributions using the FLOW-3D code. A stand-alone fuel rod code is developing to predict the thermal response of a PSBR fuel rod. The fuel rod code reads the heat generation information from the three-dimensional (3-D) neutronics code and obtains flow velocity and temperature from the CFD code, and uses these as boundary conditions.

BACKGROUNDS

There have been many calculations and experiments for the TRIGA fuel rod during steady state and pulsing operations. However, the prediction of the temperature in the pool has not been successful since the used codes do not have enough capability to model a pool type reactor, which concerns natural circulation, cross-flow, and liquid-to-liquid sheer. The temperature profile in the PSBR pool is unique along the each coolant channel. Figure 1 shows one of experimental results to measure coolant temperature profile by Haag (1971) along the coolant channels.

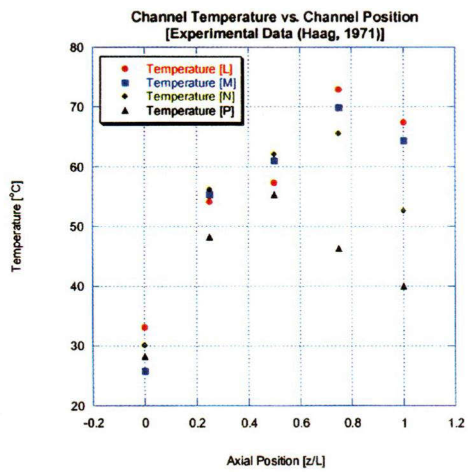

Figure 1 – Measured temperature profile along the coolant channels [Reproduced from Haag (1971)]

The channel L located near the center of the core (between the B ring and the C ring of the fuel rods). The channel P is the farthest from the center. Figure 2 represent the fuel loading and the measured coolant channel locations in Haagís research. Before the center of active fuel rods, the temperature of the coolant is almost the same even at different locations. The temperature decreases after the two-third (2/3) of active fuel rods at all four coolant channels. The explanation of this phenomenon is that a strong cross-flow comes through the edge of the core and goes up along the fuel rods.

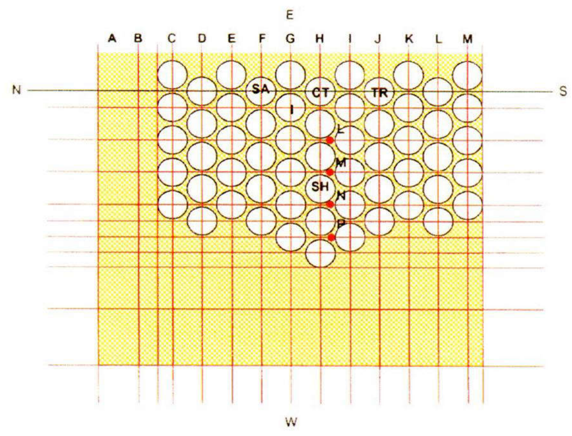

Figure 2 – Top view of the early 1970s fuel loading (gray circles are 8.5 w/o fuel rods)

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FLOW-3D MODEL

It is proposed to use a CFD code to model the PSBR pool. There have been several attempts to develop a thermal-hydraulic model to predict the temperature distribution along the coolant channels. However, the used codes do not have the capability for handling a lateral momentum of a cross-flow. The objective is to determine the flow distribution and circulation behavior with the pool and core by using a computer code. Once calculated estimates of the flow velocity is made, different types of flow measuring instrumentation can be investigate to determine a suitable measuring method in the PSBR pool.

The FLOW-3D code is an advanced CFD code developed by Harwell Laboratory in Oxfordshire, England. The FLOW-3D software is a suite of programs used for prediction of laminar and turbulent flow and heat transfer. FLOW-3D Release 2.3.2 is used in the research, which is supported by Applied Research Laboratory (ARL). One of the most important functions of FLOW-3D is the FORTRAN Front-end, which makes FLOW-3D more flexible and powerful. Even if there are complex features in a problem, they can be directly implemented to FLOW-3D by using FORTRAN subroutines.

In a FLOW-3D model, the PSBR pool is almost symmetry against the centerline. The current fuel loading (Loading 51) is perfectly symmetry. Thereby it was decided to model only the half of the whole pool. However, the heat exchanger (HX) system and the recirculation system are not perfectly symmetry. It was found that these coolant systems do not much affect the global motion of the flow.

The FLOW-3D model has fine mesh regions near the core where the flow velocities are large and more rapidly changing owing to buoyancy and the N-16 jet. The other regions were modeled as coarse mesh regions such as near the wall and below the core where the flow velocities are small and not changing significantly for different spatial locations.

For the noding sensitivity, there are two different FLOW-3D models, the proposed model (32×76×91; 233,772 volumes) and the refined model (47×136 ×161; 1,065,312 volumes). Most of calculations are performed by utilizing the proposed model and the sensitivity of the noding size is checked using the refined model. It has difficulties in using the refined model to calculate the whole CFD computations because the refined model occupies more than 500 mega-bytes (MB) of conventional memory and also requires huge computational time.

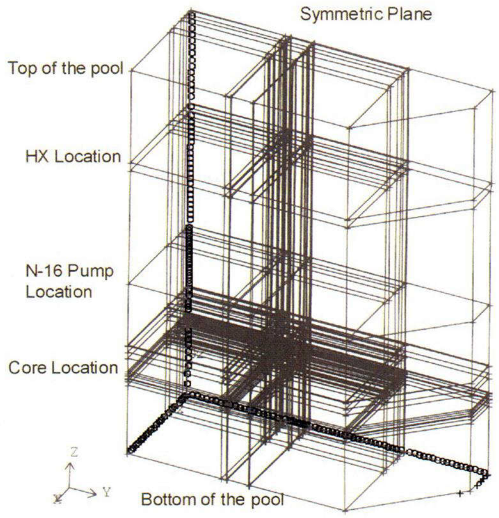

Figure 2 – Volume blocks for grid generation in GAMBIT

The pin-by-pin power distribution is superimposed on the FORTRAN subroutine of the FLOW-3D code for the normal operation of 100% power (1MW$_{th}$). There are four Dirichlet inlet boundaries and three Neumann outlet boundaries. The discharge of the recirculation system, two discharge nozzles of the N-16 pump, and the flow from the small (north) pool are considered as Dirichlet inlets of the computational domain. All the suctions of the recirculation system, the N-16 pump, and the heat exchanger are regarded Neumann outlets. A standard $k-\varepsilon$ model was used for turbulent flow. The initial guess of turbulent quantities is based on mean flow characteristics.

FUEL ROD CODE

FLOW-3D cannot easily model the detail of a fuel rod such as thermal expansion of the zirconium (Zr) bar, the fuel pellet, and the stainless-steel cladding according to power level. Therefore, an independent code will be used to model the details of the fuel rod. The advantages of a stand-alone fuel rod model are representations of the gap conductance, thermal expansion, and fission gas release. Furthermore, a stand-alone model can be used during pulsing operation as well as steady-state operation.

A stand-alone fuel rod code is a two-dimensional (2-D) heat conduction code, radial and axial, which solves the heat transfer in a cylindrical fuel rod for steady state and transient conditions. The temperature variation in the azimuthal direction is not significant inside the fuel rod compared with radial or axial. The finite volume method (FVM) was used to derive a finite difference equation from a differential form of the conduction equation. The Crank-Nicolson method guarantees 2nd-order accuracy in both space and time. This numerical method is unconditionally stable so it does not have limitation of time step size or space noding size. It also has an advantage of modeling pulsing operation since the duration of pulse is extremely short comparing with the time constant of a fuel rod and coolant. Figure 3 shows a noding scheme of a stand-alone fuel rod code, which models a full-length rod including graphite regions.

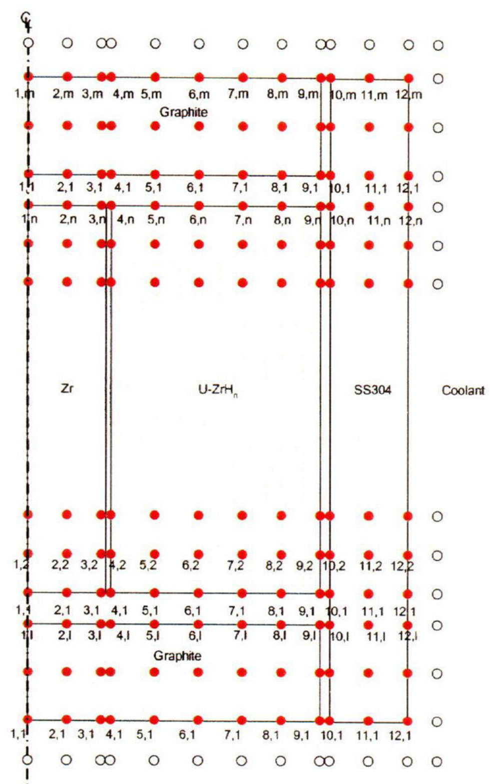

Figure 3 – Noding scheme of a stand-alone fuel rod model

A fuel rod code is written in Fortran 90, which has many enhancements compared with FORTRAN 77 such as dynamic memory allocations, modules, and array processing. A stand-alone fuel rod code consists of a main program, one input deck, two input files from the 3-D neutronics code and the CFD code, and several modules that include subroutines and functions. The gap heat transfer model and the thermal expansion model are being developed. The mechanical stress model will be applied to model thermal expansion effect. Several different gap models are considered for changing the gap heat transfer according to reactor power.

RESULTS AND DISCUSSION

The flow distribution of the PSBR pool was obtained using the FLOW-3D code. Figures 4 and 5 show the velocity and temperature distributions at the near center of the pool. It is observed that separation of the hot and cold coolant occurs below the core position although the N-16 pump is operating. The total flow through the fuel rods is calculated from the FLOW-3D results. The total flows from the side of the fuel rods and from bottom of the rods are 259 gallons per minute (gpm) and 21.5 gpm, respectively. It shows that the PSBR core is mainly cooled by the cross-flow of the coolant not by the axial flow.

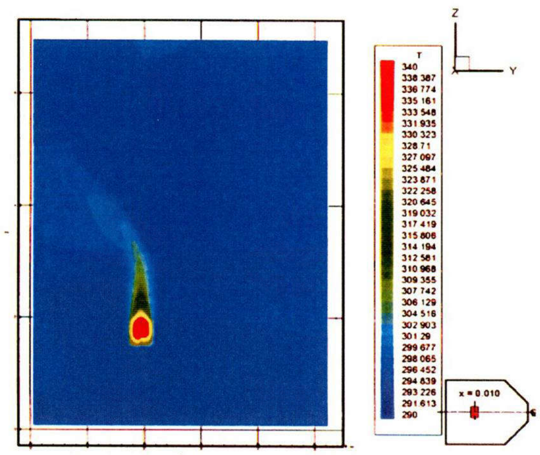

Figure 4 – Temperature distribution on the center plane of the PSBR pool (temperature in Kelvin)

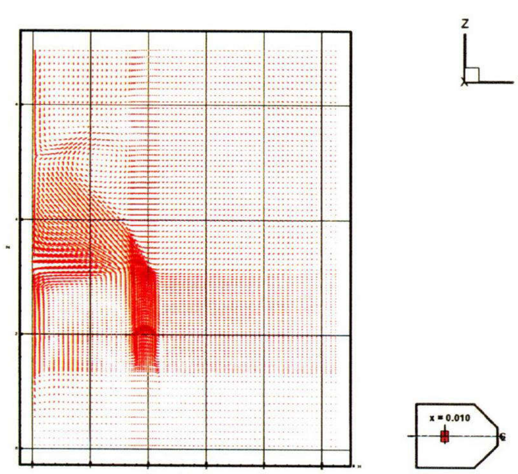

Figure 5 – Velocity distribution on the center plane of the PSBR pool

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When the PSBR was upgraded from 200 kW_{th} to 1 MW_{th} in 1965, the release of N-16 was a safety issue. N-16 has a very short half-life (approximately 7 seconds) so the N-16 diffuser was installed at the top of the core to enlarge the duration in the coolant. The flow rate of the N-16 pump was calculated based on the current version of the pump curve (L203 33) in Fig. 6. The obtained flow rate is 175 gpm during the full power operation of the N-16.

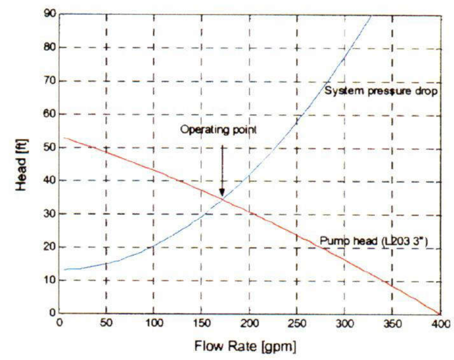

Figure 6 – Performance curve of the N-16 pump and system pressure drop

Near the center of the PSBR core (the L channel), the temperature prediction from the FLOW-3D result is quite accurate compared with the experimental data in Fig 7. The scatter bar in Fig. 7 represents the observed temperature fluctuations during the experiment, which was ± 5 °C. The trend of temperature along the channels is consistent with the experimental data in Fig. 8. It shows the decrease of coolant temperature near the top of active fuel rods. However, temperature near the edge of the core is underestimated.

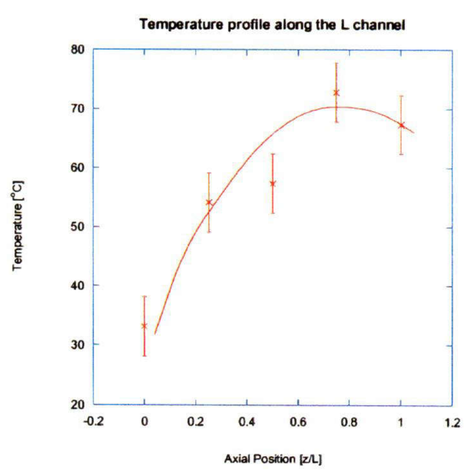

Figure 7 – Comparison of temperature profile near the PSBR core between the measured data and the FLOW-3D result

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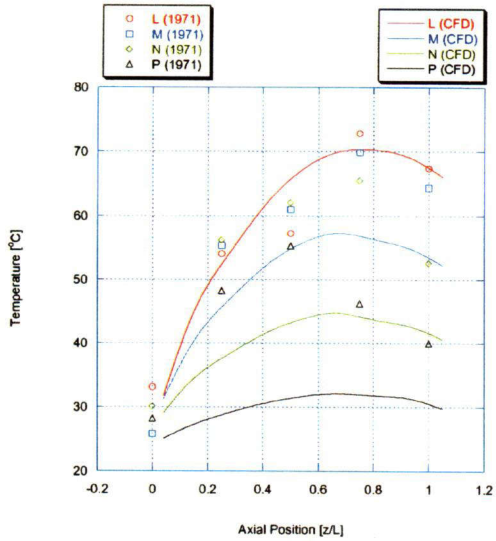

Figure 8 – Temperature profile along the coolant channel

During the above comparison, the core loading, however, is different between the early 1970s and thereafter because new fuel rods were installed in 1972. Figure 9 represents the current fuel loading (loading 51), which has two different types of fuel rods, 8.5 w/o and 12.0 w/o. Since the C ring and the D ring consist of higher weight percent fuel rods. Since the neutron flux distribution is stiff in the current fuel loading due to the higher weight percent rods, the temperature differences between channels are larger than those of the 1970s.

It is necessary to prepare the CFD prediction with the same fuel loading of the experiment and then to compare the temperature distribution along the channel. In order to produce the power distribution in the 1970s, the fuel burnup is estimated from the operation history of the PSBR and several published papers. Because there is not enough information of pin-by-pin burnup history, the average burnup will be used in the 3-D neutronics calculation.

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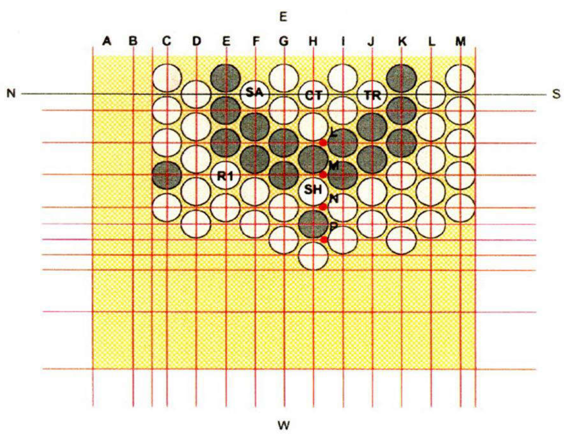

Figure 9 – Top view of the current fuel loading (bright circles are 8.5 w/o fuel rods and dark circles are 12.0 w/o fuel rods)

CONCLUSION

The thermal-hydraulic model for the PSBR is being developed. The CFD model for the PSBR pool shows the flow distribution in the pool including the velocity and temperature profiles. The FLOW-3D model shows a quite accurate temperature profile along the coolant channels compared with the previous measured data. A stand-alone fuel rod model is being developed to predict the thermal response of a PSBR fuel rod. A stand-alone model will have a capability of predicting pulsing operation as well as transient operation. The code will be coupled to the 3-D neutronics result and the FLOW-3D code. The coupled model will provide the thermal-hydraulic behavior of the PSBR core and pool.

<u>Ph.D. Thesis:</u>

Chang, J. E. and L. E. Hochreiter (advisor). Thermal-hydraulic Modeling of the Pennsylvania State Breazeale TRIGA Reactor (in progress).

<u>Publications:</u>

Chang, J. E. and L. E. Hochreiter, advisor, Thermal-hydraulic Modeling of the Pennsylvania State Breazeale TRIGA Reactor, In Progress.

Chang, J. E., L. E. Hochreiter, and T. F. Miller, Thermal-hydraulic Behavior of the Breazeale Nuclear Reactor: Core Modeling and Coupling for a Computational Dynamics Model, MNE-PSU/BNR-LR-2, July 2001.

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Chang, J. E., L. E. Hochreiter, and T. F. Miller, Thermal-hydraulic Behavior of the Breazeale Nuclear Reactor: Modeling of Recirculating Systems for a CFD Model, MNE-PSU/BNR-LR-3, August 2001.

Chang, J. E., L. E. Hochreiter, and T. F. Miller, Thermal-hydraulic Behavior of the Breazeale Nuclear Reactor: CFD Grid Generation, MNE-PSU/BNR-LR-4, October 2001.

Chang, J. E., L. E. Hochreiter, and T. F. Miller, Thermal-hydraulic Behavior of the Breazeale Nuclear Reactor: CFD Input Generation, MNE-PSU/BNR-LR-5, January 2002.

Chang, J. E., L. E. Hochreiter, and T. F. Miller, Thermal-hydraulic Behavior of the Breazeale Nuclear Reactor: CFD Calculation, MNE-PSU/BNR-LR-6, April 2002.

Chang, J. E., L. E. Hochreiter, and T. F. Miller, Thermal-hydraulic Behavior of the Breazeale Nuclear Reactor: Flow Measurement Tool, MNE-PSU/BNR-LR-7, June 2002.

NE 451, UNDERGRADUATE LABORATORY OF REACTOR EXPERIMENTS

Participants: R.M. Edwards, Professor
J.S. Brenizer, Professor
M.E. Bryan, Res. Engineer
T.L. Flinchbaugh, Manager
B.J. Heidrich, Research Asst.
C.F. Sears, Director

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

The Nuclear Engineering 451 course is the second of two 3-credit laboratory courses required of all Penn State Nuclear Engineering undergraduates and is typically taken during the Fall of the senior year. Each weekly laboratory exercise usually consists of two lectures and one laboratory session. By the beginning of the senior year, the students have already covered the LaMarsh Introduction to Nuclear Engineering text including reactor point kinetics. The 451 course emphasizes experiments using the instrumentation that was covered in NucE 450 and is divided into two (more or less) equal "tracks". These tracks can be coarsely described as TRIGA and non-TRIGA experiments and each is the major responsibility of a different professor. The non-TRIGA track includes three graphite pile, two reactor operation experiments, and a xenon poisoning simulation. In 2000, the TRIGA track included:

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

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

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

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

Participants: S.E. Cumblidge, Grad Student
A.T. Motta, Assoc. Prof.
G.L. Catchen, Prof.
G. Brauer, Institut für Ionenstrahlphysik und Materialforschung, Dresden, Germany
J. Böhmert, Institut für Sicherheitsforschung, Dresden, Germany

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

We have used using positron Doppler-broadening spectroscopy to examine a series of neutron-irradiated model alloys and 73W-weld steel. The composition of the model alloys was systematically varied in the amounts of copper, nickel and phosphorus. The 73W-weld steel contains 0.31% copper and

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

Ph.D. Thesis:

Cumblidge, S. J., G. L. Catchen (co-advisor) and A.T. Motta (co-advisor). Neutron-Irradiated Model Alloys and Pressure-Vessel Steels Studied Using Positron Spectroscopy, 2002.

Publication:

Cumblidge, S. E., G.L. Catchen, A.T. Motta, G. Brauer, and J. Böhmert,, "Effects of Neutron Irradiation and Thermal Annealing on Model Alloys using Positron Annihilation Techniques," Effects of Radiation on Materials: 20th International Symposium, American Society for Testing and Materials STP 1405, S. T. Rosinski, M. L. Grossbeck, T. R. Allen, ans A. S. Kumar, Eds., pp. 247 – 261, 2001.

PHYSICS OF FLOWING POLYMERS: DRAG REDUCTION IN TURBULENT FLOWS

Participants: G.L. Catchen, Prof.
C.C. Dey, Postdoc Scholar
J. DeJong, Grad Student
R. Colby, Prof. Mat Sci & Eng

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

Sponsor: Petroleum Research Fund of the American Chemical Society $60,000 for two years

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

Master's Thesis:

De Jong, J. and G.L. Catchen, advisor, Investigation of the Motion of Electrolytic Polymers In Aqueous Solution Using Perturbed-Angular-Correlation Spectroscopy (in progress).

COMPTON SCATTER GAUGE

Participants: E.H. Klevans, Prof. Emeritus
E.S. Kenney, Prof. Emeritus
S. Li, Grad Student
B. Wilks, Retired Volunteer

Services Provided: Laboratory Space, Machine Shop, Electronics Shop

Because of the difficulty in obtaining Hg 203 sources, and with the prospects of obtaining a new sponsor, a new source, Se-75, was provided to Penn State by Lixi Corporation. This source has multiple gamma rays, with a 401 kev gamma ray emitted 12% of the time. Other gamma rays include: 280 kev (25%); 265 kev (60%); and 136 kev (57%).

A study was conducted to determine what modifications would be required for the CSG and whether the backscatter spectrum would work satisfactorily to make measurements with the same accuracy as with Hg-203. It was determined that the internal shielding had to be increased to lower the background because of 401 Kev gamma rays penetrating the existing shield and impacting the crystal. A tungsten extension of the collimator was added and a half inch lead shield was added between the source shield and the crystal. This increased the weight by a little over three pounds, but suppressed the background to a suitable level.

It was determined that, with empty pipes, the performance was essentially as good as with Hg-203. Spectrum settings were adjusted to achieve this. With water (wax) present, the optimization of spectrum settings proved to be much more difficult, and it is not yet certain whether thickness measurements comparable to those obtained with Hg-203 can be achieved. A new and stronger source will be needed to further study the situation.

Master's Thesis:

Li, S., E.H. Klevans (co-advisor) and E.S. Kenney (co-advisor). Broad Focus Collimator Design and Use for the Compton Scatter Gauge, 2001.

IMPROVEMENTS TO THE THERMAL POWER CALIBRATION OF THE PENN STATE BREAZEALE REACTOR

Participants: B.J. Heidrich, Research Asst.
L.E. Hochreiter, Prof.
C.F. Sears, Prof.

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

Introduction:

All reactors in the United States, that are licensed by the Nuclear Regulatory Commission, must operate at a prescribed thermal power. This power is usually determined through the performance of a calorimetric procedure. This type of procedure measures the thermal power output of the reactor and the nuclear instruments are adjusted to agree with the measurement. Power reactors accomplish this by performing a heat balance with the secondary steam plant. Non-Power Reactors do not possess a steam plant and so are faced with an additional challenge. Comparisons of some of the methods by which the Non-Power Reactors have met this Nuclear Regulatory Commission requirement have been examined using the Penn State Breazeale Reactor. These methods vary from simple heat-ups of the pool water to more complex heat balances similar to the power reactor community.

The typical configuration for a Non-Power Reactor is the pool-type reactor at Penn State. This consists of a 1.0-Megawatt reactor suspended in a 71,000-gallon pool. The pool water provides both shielding and acts as a heat sink for the reactor's thermal energy.

The Pennsylvania State University Breazeale Nuclear Reactor has utilized two thermal power calibration techniques over its operating history. In 1964, I.B. McMaster, a Penn State reactor staff member, developed a thermal power calibration method for the reactor. This method was used until 1993 when K. Sahatawan developed a heat balance across the Heat Exchanger System. This is the method currently in use, with some modifications.

The purpose of this research project is to develop a more accurate and reproducible method of determining the thermal power of the Pennsylvania State University Breazeale Nuclear Reactor. This new method involves parts of present and past methods but also incorporates the following characteristics:

- The performance of the procedure will encompass at most one day of reactor time.
- The accuracy of the method will meet or exceed that accuracy of current and past PSBR methods and methods derived from several other university reactors.

- The method will allow for a high degree of precision, i.e. repeatability.
- The method will be able to be understood and performed by any knowledgeable reactor staff member.
- The method will involve a complete uncertainty analysis that will assist future work on the problem of determining the thermal power.

To achieve this goal, the following work has been performed:

- An uncertainty analysis of the current PSBR technique has been done.
- The thermal losses from the Penn State reactor system have been analyzed.
- Methods from other similar Non-Power reactors have been analyzed in detail and tested on the Penn State reactor.
- Detailed axial and radial temperature gradients in the reactor pool have been measured during various reactor operations.

Uncertainty Analysis:

The accuracy for the Heat Exchanger Primary Loop instruments are the most crucial to the accuracy of the calorimetric process. Since the Heat Exchanger System contributes >90 % of the heat removal at 400 kW and >95% at 800 kW. A 1% uncertainty in the Heat Exchanger System measurement would produce almost a 1% uncertainty in the calculated power. It would require a 10 ñ 20% uncertainty in the heat loss calculations to achieve the same uncertainty in power. As a result, more care was used in the measurement of the Heat Exchanger System parameters and very sensitive instruments were used.

The combined uncertainties in the thermal power calibration can be determined using the propagation of uncertainties as shown below.

$$Q = \dot{m} * c_p * (T_{IN} - T_{OUT}) = \dot{m} * c_p * \Delta T$$

$$\sigma_Q^2 = \left(\frac{\partial Q}{\partial m}\right)^2 \sigma_m^2 + \left(\frac{\partial Q}{\partial c_p}\right)^2 \sigma_{c_p}^2 + \left(\frac{\partial Q}{\partial T}\right)^2 \sigma_T^2$$

$$\sigma_Q^2 = \left[(c_p * \Delta T)^2 * \sigma_m^2\right] + \left[(m * \Delta T)^2 * \sigma_{c_p}^2\right] + \left[(c_p * m)^2 * \sigma_T^2\right]$$

The results of the computations are shown below.

Table 1: Accumulation of Uncertainties for the Penn State Method

System	Percent Uncertainty		Magnitude	Absolute Uncertainty
Heat Exchanger Primary Loop	1.52 %		770 kW	11.68 kW
Losses from the Surface of the Pool	Evaporation	18.62%	5.56 kW	1.04 kW
	Convection	8.74%	1.32 kW	0.06 kW
	Radiation	4.35%	7.62 kW	0.67 kW
Losses from the Pool Walls	4.66%		1.90 kW	0.09 kW
Total	1.48%		795 kW	11.75 kW

Methods from Other Reactors:

Several U.S. research reactors were polled in 2000 to determine the various methods of determining thermal power. From this research, it has been determined that there are five major methods for the thermal calibration of reactor power for research reactors. These are:

1. **Heat-Up Rate**: This method measures the heat-up rate of the reactor pool (or tank) water and uses this to calculate the heat input of the reactor. More sophisticated methods include the losses from the pool in the calculations.

2. **Heat-Up / Cool-Down Rates:** This method is a refinement of the first method. It uses a cool-down period equal to the heat-up period to cancel any thermal losses from the pool water.

3. **Change in Pool Volume**: This method requires an accurate instrument to measure the level of the pool water before and after a reactor heat-up to account for the changes in fluid density as the pool heats up. This may also be combined with a cool-down period to cancel thermal losses from the pool.

4. **Heat Balance Across a Cooling Loop:** This is the present method at Penn State. This method requires instrumented primary and secondary cooling loops and may use a digital computer to calculate the calorimetric equations.

5. **Heat Balance Across the Reactor Core:** This final method requires a closed loop for the reactor, much like a power plant. This configuration makes for the simplest and most accurate calibration. But, since is available to only a few reactors, this method will not be applied to Penn State.

One instance of each of the first four methods was researched. The examples have been chosen for the completeness of the method and for their applicability to the Penn State design. The Texas A&M method was chosen as an example of the first type. The University of Wisconsin was selected as an example of the second method. The third method was represented by the University of Missouri – Rolla. Penn State is an example of the fourth type of method.

Each method was adapted to the Penn State reactor and pool design. An uncertainty analysis was performed on each new method. The new procedure was then applied in a series of experiments. The results were analyzed and compared to the Penn State method.

The only method that showed promise was the University of Missouri procedure. The other methods are too dependent on the pool water being well-mixed. The large pool at Penn State makes this difficult to achieve. When the degree of mixing of the pool water was calculated and factored into the results, all of the procedures produced acceptable results. The only one recommended for further study is the University of Missouri method, which uses the change in pool volume to determine the thermal power. This is more of a global parameter than the localized temperature measurements of the other procedures. This reduces the reliance on pool mixing.

Axial Temperature Distribution in the Reactor Pool:

It has been suspected that a significant axial thermal gradient exists at power in the Penn State Reactor Pool. To investigate this phenomenon, a temperature probe was constructed to measure the water temperatures. The temperatures were measured in locations 1, 2 & 3 as shown on Figure 1.

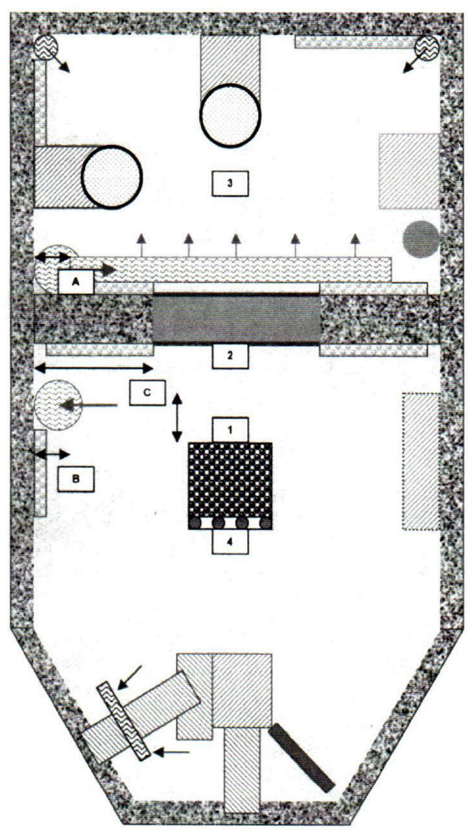

Figure 1: Reactor Pool Schematic Showing Temperature Probe Locations

The results of these measurements are shown in Figure 2.

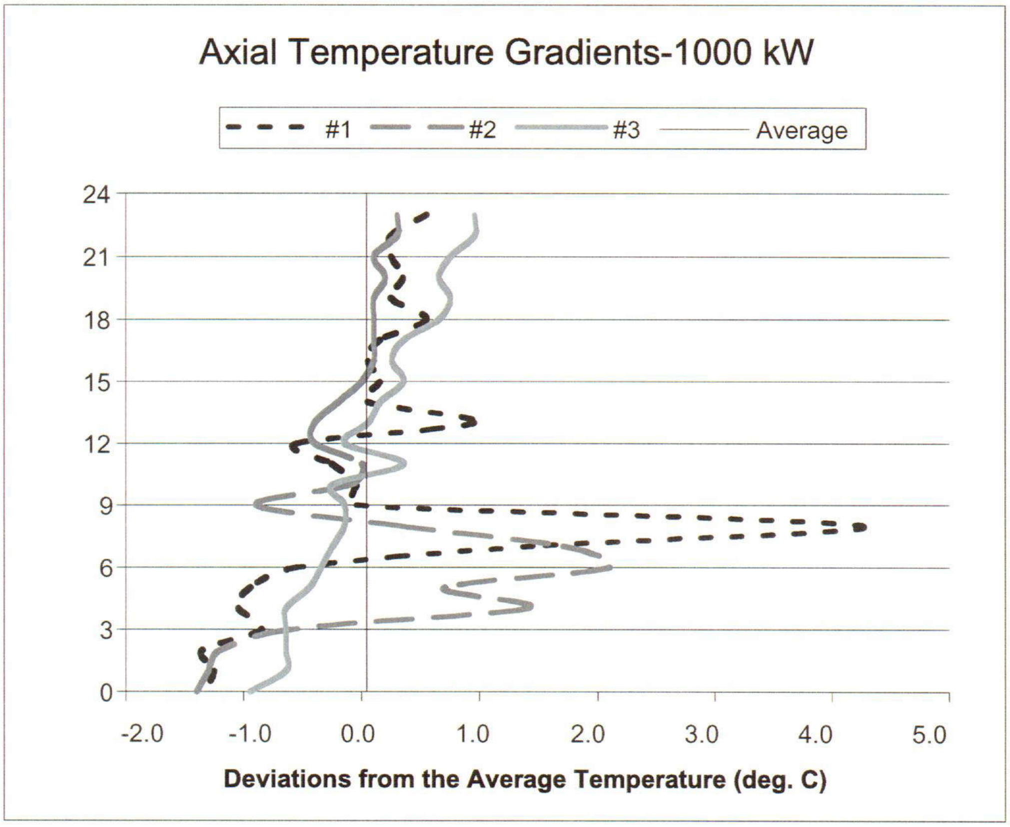

Figure 2: Axial Temperature Profile along the Pool Centerline.

It can be seen that not only does an axial temperature profile exist in the reactor pool, but the hot water from the reactor core is being blown away from the core by the N-16 diffuser pump. This effect carries across from the south pool into the north pool. This will affect the temperature distribution during a thermal power calibration.

Conclusions:

Two of the four procedures investigated show promise for Penn State. One of these is the current method of calibration with the corrected loss terms and the associated uncertainty analysis. This method is preferred because of its history of successful operation at Penn State. Also, this method is less affected by the poor mixing behavior of the pool. The operation of the heat exchanger pump mixes the pool better than in the other procedures, which do not use this system.

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However, it is difficult to perform and requires specialized equipment, both installed and experimental. Also, the effect of pool temperature on the Wide Range Power Channel must be included in any future use of this procedure, as it would with any of the other procedures. The new losses and the temperature effect will change the absolute value of the calculated power, but not the method of calibration.

The other promising method is the 'Change in Volume" procedure from the University of Missouri at Rolla. This method is simple and requires a minimum of special equipment. The measurement uncertainty for the method is 1.93% of operating power. The experimental uncertainty has proven to be 9% or 90 kW at full power when the mixing effects are accounted for. This is obviously unacceptable, but the large uncertainty is due to a number of correctable factors. The ultrasonic probe was set up for use over a large range. A smaller range should be used, or a more accurate detector obtained. Better mixing of the pool would also increase the accuracy of this method, as would a more accurate measurement of the initial bulk pool temperature. Taking this into account, this method holds the most promise for Penn State since any staff member can perform the simple procedure, with a minimum of preparation and the accuracy should be able to be increased to that of the current Penn State procedure.

The experiments and analytical work associated with evaluating the different calorimetric methods and techniques is documented in the thesis *Penn State TRIGA Reactor Thermal Power Calibration.*

<u>Master Thesis:</u>

Heidrich, B.J., Larry Hochreiter (Advisor), C. Fredrick Sears (Co-Advisor). *Penn State TRIGA Reactor Thermal Power Calibration.* In progress.

PSBR Scholarship Research Projects

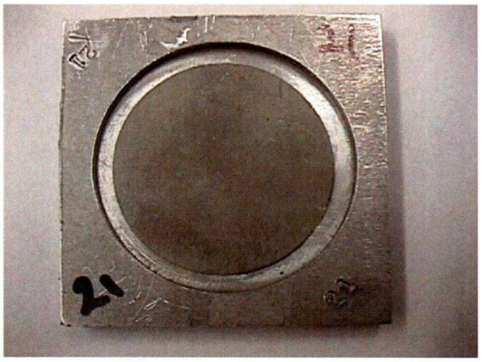
<u>QUALIFICATION OF CALIBRATION STANDARDS FOR USE IN NEUTRON TRANSMISSION</u>

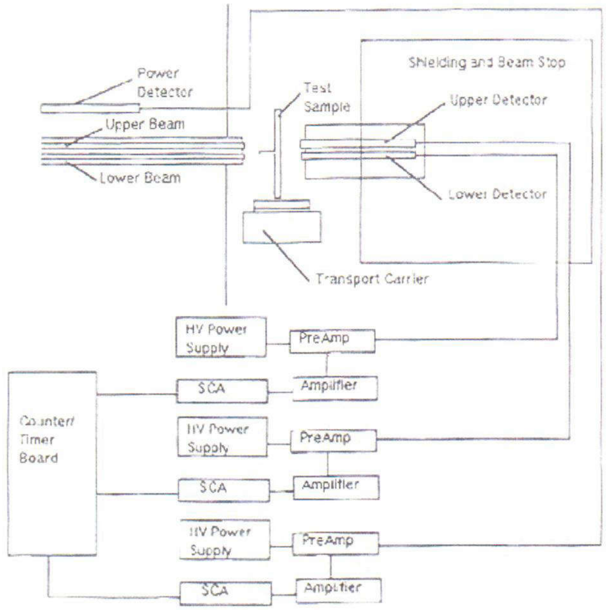
By Tristan Schaefer, Junior Undergraduate Nuclear Engineering

The certification of a set of ZrB_2 disks as calibration standards for use in neutron transmission was performed at the Breazeale Nuclear Reactor in March 2002. The University of Michigan measured the disks, provided by Eagle-Picher Industries, Inc. (EPI), in July 1997 to experimentally determine the areal density of each disk using a mono-energetic beam of neutrons at the Ford Nuclear Reactor Phoenix Memorial Laboratory. To accomplish this, each disk was placed in the beam and the attenuated neutrons were counted for 30 seconds. This counting period was sufficient in determining the areal density of the disks with an expected areal density below 37 $mg^{10}B/cm^2$. However, for the disks with an expected areal density greater than 37 $mg^{10}B/cm^2$, the 30-second counting period was not sufficient in keeping the statistical error of the areal density calculation to acceptable values.

In March 2002 the ZrB_2 disks with areal densities greater than 37 $mg^{10}B/cm^2$ were measured again at the Breazeale Nuclear Reactor. This time each disk was placed in the beam so at least 15000 *attenuated* counts were measured. The data taken from this experiment was then analyzed using two different methods. The first method, referred to as the Calculated Method, used the same equations as the computer program previously used to calculate the areal densities of the uncertified disks at the Pennsylvania State University. An excel worksheet was created to calculate the minimal and nominal areal density of the disks using the equations from this program. The second method, referred to as the Graphical Method, used the log of the corrected counts and the calculated areal densities of the original calibration standards to obtain an equation of a calibration curve. The equation of this curve was then used to determine the minimal and nominal areal density of the uncertified ZrB_2 disks. The statistical error in the areal densities obtained using these two methods was less then that obtained in the previous attempts by the University of Michigan and the Pennsylvania State University. The statistical error in the areal density of the uncertified ZrB_2 disks found using the Calculated Method was less than 4% and using the Graphical Method was less than 2%.

Following is a picture of one of the disks that was certified and the experimental set-up.





Paper Presented:

Shaefer, T. Qualification of Calibration Standards for Use in Neutron Transmission Inspections, Student ANS Conference, State College, PA, April 2002.

PERCEIVED EFFECTS ON MULTIPLICATION FACTOR COMPARED TO FISSION CHAMBER LOCATION

By: Diana Hahn, Senior Undergraduate
Kaydee Kohlhepp, Senior Undergraduate

The original objective of these experiments was to determine the perceived effects of the subcritical multiplication factor by the fission chambers during an approach to critical with the use of banked control rods. The fission chambers were placed around the outside of the core at various locations (Figure 1). These locations were to include one detector on each side of the reactor and one on the front face. There are varying amounts of fuel and moderator in-between the fission chambers and the source, which is located near the front face. Multiple experiments were conducted since only two fission chambers were available. The first experiment produced discrepancies in the data concerning the predicted point of criticality. The predictions vacillated around the accepted endpoint of criticality with some points over-predicting and others under-predicting this value. This phenomenon was studied further and became the focus of the experiments. After three experiments had been conducted, it became clear that there was a large amount of statistical error in the data collected. The plots below show the raw data and after statistical errors had been corrected.

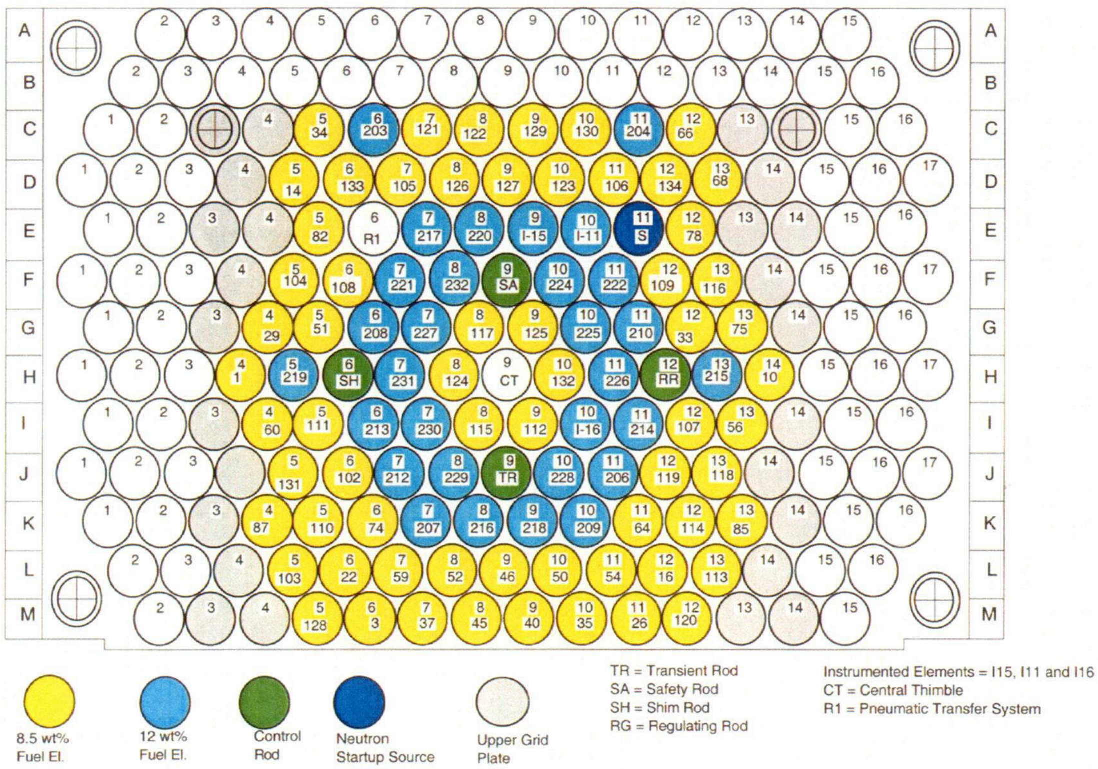
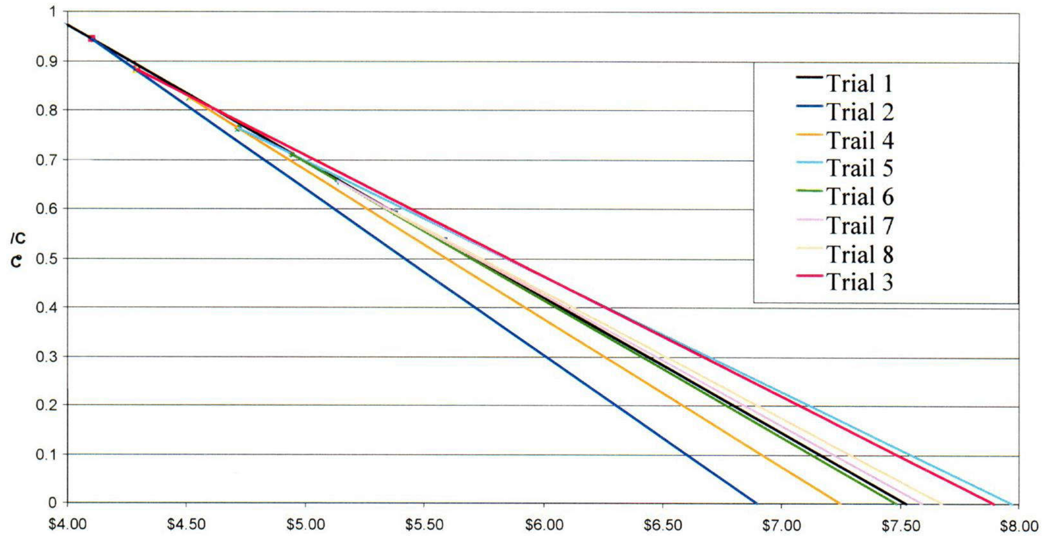


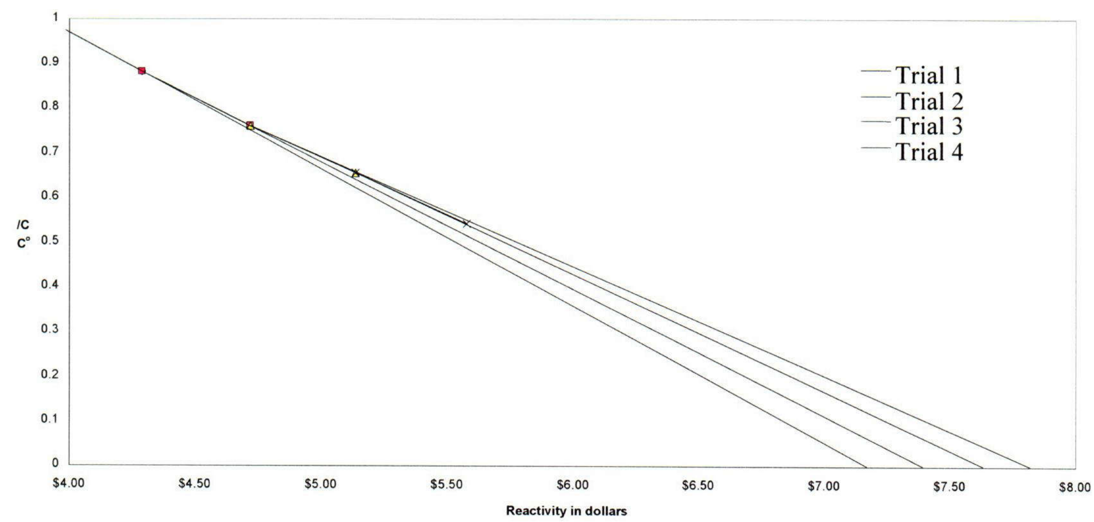
Figure 3-2 Layout of the PSBR Grid Plate (3/6/01)

Figure 1: Core layout with detector locations highlighted in red.

C16



1/M Plot for SWR
Reactivity (Experiment 3)



1/M Plot for SWR
Reactivity (Experiment 3)

Papers Presented:

Hahn, D. Perceived Effects on multiplication Factor Compared to Fission Chamber Location. Student ANS Conference, State College, PA, April 2002.

NEUTRON RADIATION RESISTANCE OF SiC: EXPERIMENTAL DEMONSTRATION

Participants: A.T. Motta, Assoc. Prof.
G.L. Catchen, Prof.
C. Tyree, Grad Student
C. Trivelpiece, UG
F. Ruddy, WEC
A.Dullo, WEC
J. Seidel, WEC

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

Sponsor: FERMI Industrial Consortium

Rapid progress has been achieved in the past decade to develop the long recognized potential of wide bandgap semiconductors such as silicon carbide (SiC) for high-temperature, high-power, and high-frequency electronics. We expect that the next generation of semiconductor electronics will be based on these new technologies. Over the past 15 years, Westinghouse Electric Corporation has been a leader in developing SiC materials and electronics through its Electronic Systems Business Unit. Specifically, Westinghouse Electric Corporation successfully demonstrated a practical technology for producing high-quality SiC. As a result of these developments, Westinghouse is pursuing the use of SiC to fabricate new neutron detectors that have superior performance in very high radiation fields. Despite the technological success associated with developing SiC detectors, we do not understand the fundamental mechanisms by which this material degrades in high neutron radiation fields.

To address this question, we have started a joint research program during the past year to explore the effects of neutron-irradiation-induced degradation of SiC radiation detectors. For this purpose, we perform in-situ electrical measurements of the response of these detectors operating in a neutron-radiation environment. In the laboratory, we perform positron-annihilation-lifetime measurements to investigate the microscopic nature of the damage and discern the nature of the damage mechanisms.

The objectives of this program are twofold: (1) to investigate the dose limits of SiC detectors at 300ΥC and 350ΥC by performing controlled irradiations while monitoring detector performance in-situ, and (ii) to investigate the nature of the damage and the associated degradation mechanisms using positron-annihilation-lifetime spectroscopy. Currently these experiments are in progress.

Senior Thesis:

Trivelpiece, C.L., A.T. Motta (co-advisor), G.L. Catchen (co-advisor). Neutron-Induced Radiation Damage in Silicon Carbide Studied Using Positron-Annihilation-Lifetime Spectroscopy (in progress).

Northeast Technology Corp.

TESTING OF NEUTRON ABSORBER MATERIALS FOR WET AND DRY SPENT FUEL STORAGE APPLICATIONS

Participants: K. Lindquist
D.Vonada
F. Sears, Prof.
J. Brenizer, Prof.
P. Rankin

Services Provided: Neutron Irradiation, Laboratory Space, X-Ray Radiography

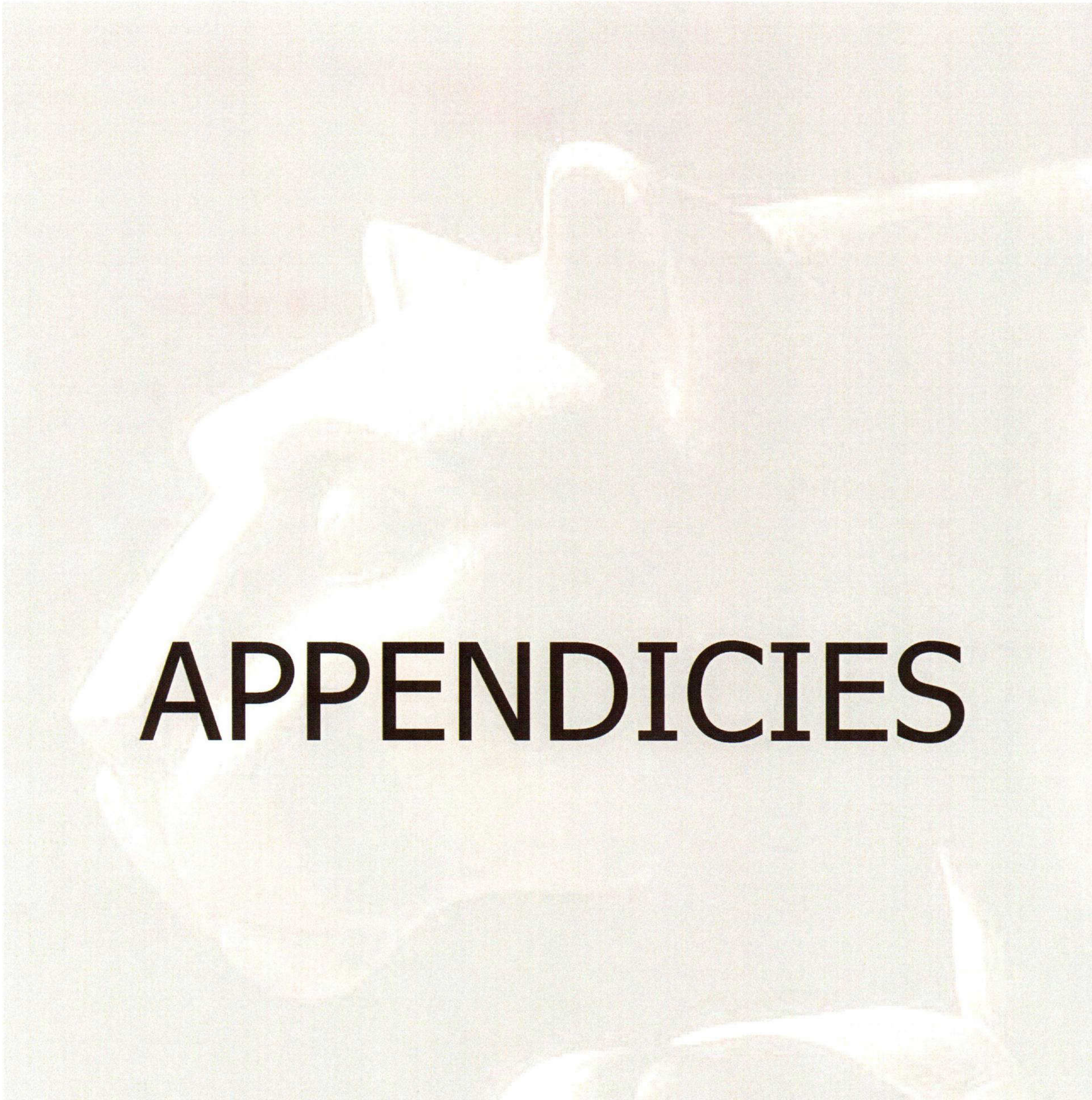
Sponsor: Electric Power Research Institute, various utilities and others.

Neutron absorber matierals such as BORAL, Boraflex, borated stainless steel and several new boron carbide/aluminum metal matrix composites are used for criticality control in spent nuclear fuel storage racks and in dry spent fuel storage and shipping casks. The work at RSEC includes qualification of new matierals such as BorTec and METAMIC for these applications as well as testing surveilance coupons of these neutron absorber materials for in-service performance verification. A key attribute which is tested is the neutron absorption capacity. This work is conducted in the Beam Hole Laboratory at RSEC.

Other atributes tested include dimensional stability, mechanical properties, elevated temperature performance and corrosion resistance. This work is ongoing.

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

University or Industry	Type of Use
Assurance Technology Corporation	Irradiation of Electronic Devices
Bettis Labs, Westinghouse	Neutron Radiography
Bio-Pore Inc.	Gamma Irradiation
Boston Scientific, Target	Neutron Radiography
COGEMA (formerly Transnucleaire, France)	Neutron Radiography Neutron Radioscopy Neutron Transmission
Commonwealth Edison Company	Compton Scatter Gauge Development
Eagle-Picher	Neutron Radiography Neutron Radioscopy Neutron Transmission
Exxon Research Corporation	Compton Scatter Gauge Development
Fairchild Corporation	Semiconductor Irradiation
Institut für Ionestrahlphysik and Materialforschung, Dresden, German	Perturbed Angular Correlation
Institut für Sicherheitsforschung, Dresden, Germany	Perturbed Angular Correlation
Instituto de Fisica, Rio Grande do Sul, Brasil	Perturbed Angular Correlation
Instituto de Fisica, Sao Paulo, Brasil	Perturbed Angular Correlation
Lockheed Martin	Semiconductor Irradiation
National Institute of Technology	Console Demonstration
NETCO (Northeast Technology Corporation)	Neutron Radioscopy Neutron Transmission
Nuclear Management Corporation, Point Beach Station	Neutron Transmissions
Westinghouse Electric Corporation	Irradiation of Electronic Devices
Oglevee Ltd.	Gamma Irradiation
Physical Acoustics Corporation	Irradiation of Electronic Devices
Quality Services Laboratory Plus	Irradiation of Electronic Devices
Raytheon Company, Sudbury, MA	Irradiation of Electronic Devices
Raytheon Systems Company, El Sequndo, CA	Irradiation of Electronic Devices
Synetix	Isotope Production
Tru-Tec	Isotope Production
TRW	Semiconductor Irradiation
University of Pittsburgh, Greensburg	Neutron Activation Analysis
Westinghouse Savannah River	Neutron Radiography



APPENDICIES

APPENDIX A

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

COLLEGE OF AGRICULTURE	
Agriculture & Biological Engineering:	
Demirci, Ali	F
Irudayaraj, Joseph	F
Puri, Virendra M.	F
Kazil, Ramazan	G
Krishnamarthy, Kathirivan	G
Food Science & Technology:	
Cutter, Catherine N.	F
Beelman, Robert	F
Perkowski, Kenneth	G
Montella, John	G
Mills, Edward	F
Horticulture:	
Koide, Roger	F
Wakefield, Erin	G
Wu, Tiehang	G
Plant Pathology:	
Juba, Jean	S
Veterinary Science:	
Corl, Christine	G
Sordillo, Lorraine	F

COLLEGE OF EARTH & MINERAL SCIENCE	
Material Science & Engineering:	
Harrison, Ian	F
Colby, R.	F
Montgomery, Stephen	F

COLLEGE OF ENGINEERING	
Bio-Engineering:	
Graumond, Roger	F
Industrial Engineering:	
Cannon, Dave	F
Petrick, Irene	F
Mechanical & Nuclear Engineering:	
Adamonis, Jaclyn	U
Baratta, Anthony	F
Brenizer, Jack	F

Mechanical & Nuclear Engineering (cont.):	
Bryan, Mac	S
Buschman, Francis	U
Butler, Jennifer	U
Catchen, Gary	F
Cecenas-Falcon, M	G
Cetiner, Sacit	G
Chang, Jong Eun	G
Chaung, Abel	G
Chesleigh, Marcia	U
Cimbala, John M.	F
Cumblidge, Stephen	G
Daubenspeck, Thierry	S
Davison, Candace	S
Decker, Chandra	U
DeJong, Jerome	G
Dey, Chandi	PD
Eaken, Ronald	S
Edwards, Robert	F
Ergin, Sule	G
Flinchbaugh, Terry	S
Grapes, Chris	U
Grieb, Mark	S
Haghighat, Ali	F
Hahn, Diana	U
He, Weidong	G
Heidrich, Brenden	G
Hochreiter, Larry	F
Huang, Zhengzyu	G
Ireland, Andrew	U
Ivanov, Kostadin	F
Jang, Jehun	G
Jurgensmeier, Sarah	G
Kenney, Edward	FE
Klevans, Edward	FE
Kohlepp, Kaydee	U
Kriangchaiporn, Nateekool	G
Lebiedzik, Jana	S
Lee, K.Y.	G
Li, Shi	G
Marcy, Melissa	U
Marenchin, Tom	U

Mechanical & Nuclear Engineering (cont.):	
Santavicca, Domenic	F
Schaeffer, Roman	G
Sears, C. Frederick	F
Shyu, S	G
Tippayakul, C	G
Todd, Matt	HS
Vincenti, John	S
Werkheiser, Dave	S/G
Whisker, Vaughn	G
Williams, Jason	U
Wilks, Ben	S

COLLEGE OF SCIENCE	
Chemistry:	
Allcock, Harry	F
Bender, Jared	G
Chalkova, Elena	G
Mwita, Phelps	G
Reed, C.S.	F
Young, Kyu Chang	PD
Yunei, Bi	VS
Biology:	
MacIver, Ian	PD
Ma, Hong	G
Thomas, Graham	F

COLLEGE OF LIBERAL ARTS:	
Anthropology:	
Bondar, Gregory	G
Donaldson, Christopher	U
Hirth, Kenneth	F
Psychology:	
Peck, Andrew	F

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

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

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

USDA - ARS	
McDonnell Richard	F
Saporito, Louis	F

MATERIALS RESEARCH LABORATORY	
Jeong, Dae-Young	G
Scheetz, Barry	F
Zhang, Qi-Mong	G

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

INDUSTRIES, ETC.	
Assurance Technology Corporation	Bob Brine Cosmos Cicaccio
Bettis Labs, Westinghouse	Tom Conroy
Bio-Pore, Inc.	Palmer Cramer Steve Schwartz
Boston Scientific, Target	Clifford Teoh
COGEMA (formerly Transnucleaire, France)	Gilles Bonnet Guillaume Bostetter Rene Chiocca Laurent Lamps Jean Oudot Philippe Naigeon Loic Servant
Eagle-Picher	Monte Hart Jerry Houdyshell
Fairchild Corporation, Mountaintop, PA	Frank Kalkbrenner Joe Macieunas
Institut für Sicherheitsforschung, Germany	Jurgen Böhmert
Institute für Ionestrahlphysik and Materialforschung, Germany	Gerhard Brauer
Lockheed-Martin	Alex Bogorad Robert Gigliuto
National Institute of Science and Technology (NIST)	Jim Boyd Barry Caudle
Northeast Technology Corporation	Matt Harris Ken Lindquist Doug Vonada
Nuclear Management Company, Point Beach Station	John Broschak
Oglevee, Ltd.	Ed Mikkelsen
Physical Acoustics Corporation	Mark Carlos Weiming Dai
Quality Services Laboratory Plus	Michael Lange
Raytheon	Angela McMaster Stewart Mulford
Raytheon Systems Company	Ed Craig
Synetix	ScottVidrine
Tru-Tec	Mike Flenniken Jerre Kolek
TRW	Russ Graham Don Randall
University of Pittsburg, Greensburg	Tim Savisky Ted Zaleskiewicz
Westinghouse Electric Corporation	Abdul Dulloo Frank Ruddy John Seidel
Westinghouse Savannah River	Kenneth Gibbs

APPENDIX B

FORMAL TOUR GROUPS

Group Name	Date	# Visitors
PGSAS	07/05/01	35
PGSAS	07/06/01	35
Student Tour	07/06/01	3
Upward Bound	07/10/01	28
Upward Bound	07/10/01	28
Public Information	07/11/01	1
Student Exchange Program	07/11/01	1
Frank Buschman's Family	07/13/01	2
DeSanto Tour	07/13/01	1
Nuclear Science & Tech Course	07/18/01	10
CALL	07/20/01	25
Swagelok	07/20/01	1
Agricultural Engr.	07/20/01	2
Human Resources	07/23/01	3
Spend a Summer Day	07/23/01	4
ED & G 100 (Leap Program)	07/24/01	8
RECEP Course Teachers	07/24/01	9
RECEP Students	07/25/01	13
Leap Program	07/26/01	21
Spend a Summer Day	07/27/01	12
Sears Family	07/28/01	7
Spend a Summer Day	07/30/01	3
Spend a Summer Day	07/30/01	19
Spicer Family	08/01/01	2
Sam Levine's Family	08/03/01	3
Spend a Summer Day	08/03/01	2
Spend a Summer Day	08/03/01	21
Randy McCullough's Family	08/03/01	6
Adventure Daycamp	08/07/01	46
Personal-Marcia Chesleigh's Family	08/13/01	3
Compton Scattergauge Group	08/14/01	3
Student Tour	08/20/01	1
NucE 001	08/21/01	20
Student Tour	08/21/01	2

Group Name	Date	# Visitors
Student Interview	08/23/01	1
Student	08/24/01	1
Naval Reactors	08/28/01	3
Personal	08/29/01	7
Gamma Irradiation-Horticulture Dept.	09/04/01	1
Student	09/06/01	1
Student	09/06/01	1
ANS Meeting	09/06/01	5
NucE 430 Group Meeting	09/06/01	1
NucE 401	09/07/01	9
NucE 401	09/07/01	7
097-Engineering Seminar	09/10/01	15
DEP	09/11/01	11
Student	09/11/01	1
PSU Faculty	09/11/01	1
NucE 401	09/12/01	15
IE408W	09/13/01	1
Exelon	09/13/01	1
Framatome	09/13/01	2
ACURI Meeting	09/18/01	1
NucE 301	09/19/01	21
Westinghouse	09/20/01	4
Framatome	09/20/01	2
IE408W	09/20/01	13
IE408W	09/20/01	9
IE408W	09/21/01	12
IE408W	09/21/01	9
Student	09/21/01	1
IE408W	09/21/01	15
IE408W	09/21/01	11
Student	09/24/01	1
NucE	09/26/01	1
IE 408	09/28/01	2
Open House	09/29/01	304

APPENDIX B

FORMAL TOUR GROUPS

Group Name	Date	# Visitors
DEP	10/02/01	1
DARPA Tour	10/03/01	3
Personal-Dave's Friend	10/04/01	1
Miller Tour	10/05/01	2
Biology	10/05/01	2
Girl Scouts	10/08/01	12
Personal-Chanda Decker's Family	10/09/01	1
Bellefonte High School	10/11/01	1
Civil & Environmental Engineering	10/11/01	3
AG 150S	10/15/01	17
Personal-Mark Grieb's Family	10/20/01	1
Engineering Open House	10/20/01	3
Engineering Open House	10/20/01	3
Engineering Open House	10/20/01	3
Engineering Open House	10/20/01	2
Engineering Open House	10/20/01	3
Engineering Open House	10/20/01	2
Engineering Open House	10/20/01	2
Engineering Open House	10/20/01	4
Engineering Open House	10/20/01	3
Boy Scout Tour	10/20/01	8
Morgan State University	10/20/01	6
Engineering Open House	10/20/01	2
Engineering Open House	10/20/01	1
Engineering Open House	10/20/01	2
Engineering Open House	10/20/01	3
Engineering Open House	10/20/01	3
Engineering Open House	10/20/01	1
Engineering Open House	10/20/01	4
Engineering Open House	10/20/01	3
Food Science ISTS 105	10/22/01	9
PSRC Audit	10/22/01	1
Center Region COG	10/24/01	1
Karen King-Calligrapher	10/25/01	1

Group Name	Date	# Visitors
Personal-Mike Morlang's Family	10/26/01	2
Houserville Elementary School	10/30/01	26
Houserville Elementary School	10/30/01	27
Houserville Elementary	10/30/01	24
Daily Collegian	10/31/01	2
M & NucE	10/31/01	1
DOE	11/01/01	2
Westinghouse	11/02/01	4
Fairmount Elementary School	11/05/01	26
ED 100S	11/06/01	16
Biology	11/07/01	1
Bellefonte High School	11/08/01	1
Lowry Family Tour (student's parents)	11/09/01	2
Environmental Health and Safety	11/13/01	1
Food Science Class	11/15/01	24
Ligonier Valley High School	11/15/01	38
Combustion Lab	11/15/01	3
NRC	11/16/01	2
IE 430	11/16/01	1
Quality Services Lab Plus	11/20/01	1
High School Students	11/26/01	4
Park Forest Middle School	11/27/01	24
Park Forest Middle School	11/27/01	26
Park Forest Middle Schoool	11/27/01	25
Seminar Speaker and student	11/29/01	2
Daily Collegian	11/29/01	2
Engr 100 S	11/29/01	22
West Halls (EMS Interest House)	11/29/01	12
Public Information	11/30/01	3
Park Forest Middle School	12/04/01	23
Park Forest Middle School	12/04/01	24
Park Forest Middle School	12/04/01	26
PSTA Planning Meeting	12/04/01	1
Student	12/11/01	1

APPENDIX B

FORMAL TOUR GROUPS

Group Name	Date	# Visitors
NIST Reactor	12/13/01	2
Steven Biezalski	12/14/01	1
Northrup Grummon	12/18/01	5
University of Pittsburgh-Greensburg	12/18/01	2
Bellefonte High School	12/20/01	1
EHS	12/21/01	1
Freshman Seminar	01/10/02	20
Faculty Candidate	01/11/02	1
Safeguard's Meeting	01/15/02	7
Interviewee	01/15/02	1
Engr. Students	01/17/02	5
Student	01/18/02	1
ARL	01/24/02	1
Biology	01/29/02	1
Nittany Oil	01/30/02	2
Biology	01/30/02	1
ARL	01/31/02	1
ASAE	01/31/02	17
Faculty Candidate	02/01/02	1
EHS	02/01/02	1
Hollidaysburg High School	02/07/02	2
Brockway High School	02/08/02	15
NucE 307	02/11/02	2
EHS	02/12/02	1
University Development	02/13/02	1
IE 408W	02/13/02	25
Marcus Wendehog	02/14/02	1
IE 408	02/14/02	21
Dept. Speaker	02/14/02	1
IE 408W	02/14/02	23
Engineering Psychology	02/15/02	22
Personal-Staff Families	02/15/02	6
Vet Science	02/19/02	1
MNE Faculty Candidate	02/22/02	1
ME 30	02/25/02	4
Huntingdon High School/PAJSHS	02/25/02	14
Lixi Corp.	02/27/02	2
Faculty Candidate	02/28/02	1
Student	03/11/02	1
Personal-Dave's friend	03/15/02	1
Engineering Open House	03/16/02	8
Engineering Open House	03/16/02	10
PSU NucE Alumni	03/16/02	2
Engineering Open House	03/16/02	12
Engineering Open House	03/16/02	11
Engineering Open House	03/16/02	4
Engineering Open House	03/16/02	1
Engineering Open House	03/16/02	6
Engineering Open House	03/16/02	7
Engineering Open House	03/16/02	8
Police Services	03/18/02	4
State College Area High School	03/19/02	40
Aberdeen	03/19/02	2
Eastern Lebanon County	03/19/02	3
Students	03/20/02	2
CSG	03/20/02	1
Human Resources	03/20/02	2
Tyrone High School	03/21/02	30
Tyrone High School	03/21/02	29
Personal-Dey's Wife	03/21/02	1
Greensburg Salem High School	03/22/02	20
Prospective Student	03/22/02	1
CSG	03/22/02	1
Boy Scouts Tour Guides	03/23/02	4
Boy Scouts	03/23/02	11
Boy Scouts	03/23/02	4
Boy Scouts	03/23/02	9
Boy Scouts	03/23/02	5

APPENDIX B

FORMAL TOUR GROUPS

Group Name	Date	# Visitors
Boy Scouts	03/23/02	5
NucE 307	03/25/02	1
Univ. of Pitt Greensburg	03/25/02	4
Alumni	03/25/02	1
State College High School	03/26/02	38
Punxsutawney High School	03/27/02	8
Prospective Student	03/28/02	2
Boy Scouts	03/28/02	2
NucE 307	04/01/02	2
National University of Mexico	04/01/02	1
Promethean Life Sciences	04/02/02	1
Boy Scouts	04/02/02	11
Daniel Boone High School	04/04/02	15
CPI	04/05/02	13
CSG	04/08/02	1
Student	04/08/02	1
Grove City College	04/09/02	9
Kane High School	04/12/02	11
ANS Conference Tours	04/13/02	114
Food Science 415	04/15/02	6
Food Science 415	04/15/02	2
OEA	04/15/02	1
Food Science	04/16/02	1
ME-30	04/17/02	1
Juniata College	04/17/02	9
Wyomissing High School	04/17/02	10
Park Forest Middle School	04/18/02	24
Park Forest Middle School	04/18/02	21
Park Forest Middle School	04/18/02	21
Shepard College	04/18/02	8
St. Mary's High School	04/19/02	33
PSU Alum	04/19/02	2
Personal-Brenizer's Friends	04/19/02	2
COE Alumni	04/20/02	14

Group Name	Date	# Visitors
COE Alumni	04/20/02	12
Red Lion Christian Academy	04/23/02	14
Interviewee	04/23/02	1
Williamson High School	04/24/02	21
Personal-Jeremy's Friend	04/24/02	1
Personal-Randy's Family	04/25/02	1
Take Your Daughter to Work Day	04/25/02	8
Bursar's Office	04/25/02	11
Take Your Daughter to Work Day	04/25/02	1
Chemistry-Altoona Campus	04/25/02	6
Moshannon Valley High School	04/26/02	12
North Potter High School	04/29/02	19
Human Resources	04/29/02	1
NucE/ME	04/30/02	1
Germany	04/30/02	4
Grad Student	05/02/02	1
Elderhostel	05/02/02	37
North Eastern High School	05/08/02	15
EMS	05/09/02	1
Huntingdon High School	05/09/02	18
Erie Insurance	05/09/02	1
Personal	05/10/02	13
Spring Grove High School	05/13/02	19
University Pitt at Greensburg	05/15/02	2
FERMI	05/17/02	9
Camp Hill High School	05/17/02	21
Danville High School	05/20/02	9
PSU Students	05/20/02	2
NETC	05/20/02	8
ME Faculty	05/23/02	1
Sandia National Lab	05/28/02	1
Cornell University - Interviewee	05/28/02	1
EFMR	05/28/02	1
Student	05/31/02	1

APPENDIX B

FORMAL TOUR GROUPS

Group Name	Date	# Visitors
Retiree	06/04/02	1
College of Science	06/06/02	2
MNE	06/07/02	1
Westinghouse	06/11/02	2
ELCO	06/13/02	16
Reed College	06/14/02	2
Earth & Mineral Sciences	06/18/02	2
PC Express	06/20/02	1
VIEW	06/20/02	26
WISE	06/20/02	28
Health Physics Interviewee	06/24/02	1
VIEW	06/27/02	21
Environmental Science Camp	06/28/02	30
Brookhaven National Lab	06/28/02	1
		2641

* 168 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.)