PU/NE-04-14

*U. S. Department of Energy
University Nuclear Science & Reactor Support*

**UPGRADE OF INSTRUMENTATION FOR
PURDUE REACTOR PUR-1, PHASE 3**

Project Carried Out With Support From US DOE Under

Award NO: DE-FG07-02ID14303

**Final Report
August 1, 2002 to July 30, 2004**

S. T. Revankar

PURDUE
UNIVERSITY

SCHOOL OF NUCLEAR ENGINEERING

U. S. Department of Energy University Nuclear Science and Reactor Support

Upgrade of Instrumentation for Purdue Reactor PUR-1, Phase 3

**Final Report
August 2002 to July 2004**

Contact: Dr. Shripad Revankar
School of Nuclear Engineering
Purdue University
West Lafayette, In 47907-1290

Contributing Authors:

S. T. Revankar*
*Purdue University
School of Nuclear Engineering
West Lafayette, IN 47906-1290*

* *Principal Investigator*

CONTENTS

List of Figures	iii
List of Tables	iii
Executive Summary	iv
Acknowledgement	v
1. Introduction	1
2. Objectives	3
3. Current Instrumentation	5
3.1 Reactor Control System	5
3.2 CSA Electronics Status	6
4. Project Description	7
4.1 Convert the Control and Safety Amplifiers (CSAs) to Solid State Electronics	7
4.2 Upgrade and Replacement of Instrumentation Chassis and Radiation Monitor	7
4.3 Upgrade of Channel Three and Interface for Channel Four	8
5. Project Status	13

LIST OF FIGURES

Figure 1. Circuit card layout	14
Figure 2. Typical circuit board received and the plated through	14
Figure 3. Eyelets installed and the edge connector installed.	15
Figure 4. Fabricated box, which will house the new circuits.	15
Figure 5. The two chassis to be replace by the new chassis	16

LIST OF TABLES

Table 1 PUR-1 Information	2
Table 2 List of Project and Equipments	12

EXECUTIVE SUMMARY

The major objective of this program is to upgrade and replace instruments and equipment that significantly improve the performance, control and operational capability of the Purdue University nuclear reactor (PUR-1). Under this major objective one project on design and installation of interface cards for channel four detector was considered.. This report is the final report and gives the efforts and progress achieved on these projects from August 2002 to July 2004.

ACKNOWLEDGEMENT

This report was prepared with the support of the U.S. Department of Energy (DOE) with award number DE-FG07-02ID14303. However, any opinion, findings, conclusions, or recommendations expressed herein are those of the author and do not reflect the views of DOE.

1. INTRODUCTION

The Purdue University Reactor (PUR-1) is the first and only operating reactor in the state of Indiana. Purdue University operates it under the direction of the School of Nuclear Engineering. PUR-1 is a 1 kW swimming pool reactor that was built in the early 1960's for research and training. Some of the characteristics and information of the PUR-1 are given in Table 1. The current usage of the reactor is primarily education of the public and teaching reactor concepts to students in nuclear fields (Nuclear Engineering, Health Physics, etc.). This includes classes taught in the reactor room, classes in the adjoining radiation laboratory, students operating the reactor for experiments, and tours for the public.

The reactor and its counting laboratory are used by the School of Nuclear Engineering to teach undergraduate and graduate-level radiation detection techniques and procedures, as well as to teach reactor physics. The School of Nuclear engineering has a fall 2001 enrollment of 95 undergraduate students and 35 graduate students. The reactor is an integral part of the education for bachelor's degrees, and many graduate students are required to take the reactor course as part of their plan of study. During the reactor kinetics portions of the courses, the students operate the reactor while making period and reactivity measurements. The reactor is also used to assist the School of Science in teaching their Reactor Health Science laboratory course. Those students (approximately 10-15 per class, 3 classes per semester) use the reactor to irradiate samples for reactor flux and detector efficiency calculations, as well as learning how to calibrate our area monitors and change the filters on the continuous air monitor. Finally, the reactor is often the subject of student design projects. The students create computer models and use the reactor's experimental data to compare the accuracy of their models. This included the creation of a PC based simulator in 1996 and a study of the planned conversion to Low Enriched Uranium in 1998 and design of a reactivity monitor in 2002.

The public is often invited for tours of the reactor facility. The Student Chapter of the American Nuclear Society hosts a Nuclear Week each fall semester that includes reactor tours. The School of Nuclear engineering actively participates in summer programs at Purdue for Junior High and High School students to learn more about science and engineering. These programs involve approximately 150 students each summer. Additionally, the reactor is used for the DOE Reactor Sharing Program. Groups of high school students (10-14 groups of 12 students

each) spend a day learning how to do neutron activation analysis. They irradiate samples in the reactor and use scintillation detectors to identify the elements present in their sample. All of these programs have been in place and operating successfully for at least the last four years. The average number of total visitors to the reactor over the previous three years was 359 per year; the average number of visitors since 1997 has increased to 1000.

TABLE 1. PUR-1 INFORMATION

Reactor	PUR-1
Docket Number	50-182
Contractor	Lockheed Nuclear Products
First Critical	August 31, 1962
Licensed Power level	1 kW
Core Size	1 ft x 1 ft x 2 ft
Max. Thermal Flux	2.1×10^{10} n/cm ² -sec at 1 kW
Fuel Type	Flat Plate
Cladding	1100 Al
Moderator	Light Water
Reflector	Light Water and Graphite
Excess k_{eff} (max)	0.6%
Excess k_{eff} (admin.)	0.3 to 0.5%
Control Rods	3
Reg. Rod (1)	304 SS
Shim Rods (2)	Boron SS
Travel Speed RR	17.7 in/min
SS	4.4 in/min
Rod Drop Time (max)	1 sec.
Tank Size	8 ft Dia. x 17 ft Deep 6400 gal. Of Water
Pump Capacity	30 gal/min
Instrumentation Channels	4
Area Monitors	3
Air Monitor	1

2. OBJECTIVES

The major objective of this proposal is to upgrade and replace instruments and equipments that significantly improve the performance, control and operational capability of the Purdue University nuclear reactor PUR-1.

In order to achieve this objective the instrument upgrade and replacement has been planned in several phases. These are listed below in order of priority.

Phase 1: Under phase 1, the replacement of vacuum tube based Control and Safety Amplifiers (CSAs) to solid-state electronics has been planned. This phase of the project was partly funded. The description of project under phase 1, the tasks involved and the progress are given in the following section 2.3.1.

Phase 2: under this phase, upgrading of the instrumentation chassis has been planned. Specific projects under this phase are:

- (1) Replace three old radiation area monitors with new monitors,
- (2) Replace one old continuous air monitor with new monitor,
- (3) Add four new high deflection angle meters as display meters for the console,
- (4) Add one personal computer based data acquisition and display system,
- (5) Replace the uncompensated BF_3 detector with a new compensated ionization chamber for channel three, the linear channel.

Under this phase, funding for projects (3) to (5) and for project (1) one radiation monitor replacement was requested. This phase of project has been funded. The Purdue University has provided funding for the two radiation area monitors (project 1) and one continuous air monitor (project 2). The description of project under phase 2, the tasks involved and the progress are given in the following section 2.3.2.

Phase 3: under this phase, the upgrade project will tie in all of the new systems acquired as well as continue replacement and upgrade of the equipment. It is expected that this phase run through series of upgrade plans. For this requested funding period, the following projects are planned:

- (1) Install a micro-micro-ammeter capable of reading compensated ionization chamber during reactor shutdown with source in.

- (2) Design and install interface cards for channel four detector and channel two period outputs.

Under this phase funding for item (1) namely micro-micro-ammeter was awarded.

Phase 3 Continuation: This phase is the continuation of phase 3, which would aim at completing the instrument upgrade program. Since the item (2) in phase 3 was not funded, the funding for the following project was requested.

- (1) Design and install interface cards for channel four detector and channel two period outputs.

3. CURRENT INSTRUMENTATION

3.1 Reactor Control System

PUR-1 has four instrument channels. As per technical specifications channel is referred to denote a neutron sensitive detector, its cabling connections and the associated electronics to analyze and display the output. Channel 1 is the startup channel. It consists of a fission chamber with the output converted to log count rate and period information. Channel 2 is a compensated ionization chamber that produces Log N and period information. The safety circuits switch over to Channel 2 (from Channel 1) when the Channel 2 level meter comes on scale. Channel 2 remains on scale up to 120% of power. Channel 3 is a BF_3 (uncompensated) detector that inputs to a linear level meter. This allows the operator a linear readout as well as providing linear input to an automatic leveling control system. Channel 4 is the safety channel. Channel 4 is a BF_3 (uncompensated) detector that does not display its output directly to the operator at the console. The safety channel output is used only for monitoring by the scram circuitry.

The central part of the scram safety system is two Control Safety Amplifiers (CSAs). CSA-1 is the level safety system. It monitors Channel 4. CSA-1 supplies the electromagnet power for Shim Safety rod 1 (SS1) and will trip both safety rods on a Channel 4 reading of 120% power level. CSA-2 is the period safety system. Taking input from Channel 1 and Channel 2, CSA-2 will trip the shim safety rod magnet at a period of 7 seconds. A bus connects the two CSA chassis such that a trip condition on one will result in a trip of the other, dropping both SS1 and SS2. Additionally, other scram trip alarms are routed through CSA-1 and CSA-2. 120% power from Channel 2, 120% linear range from Channel 3, trouble (disconnected cable), high radiation alarm from the area monitors, low alarm from the area monitors, etc., will all cause a scram trip condition in CSA-1 and CSA-2.

3.2 CSA Electronics Status

The electronics of the CSA's consists of 1950's vacuum tube technology. There are serious problems with this old technology, specifically, lack of availability of replacement parts and repairs. Many of the vacuum tube devices are obsolete. Some of the tubes are not available in the standard electronics outlets and are difficult to procure. It is hard to find maintenance technicians for this vintage electronics. The vacuum tube electronics is based on a high voltage system (~120 volts DC), and signal outputs are not available. Thus, these units cannot be easily interfaced to computer (PC) based data acquisition systems and display. It should be noted that the CSAs are the key safety system of the reactor. They control the magnet currents for the shim safety rods. The trip signals from all other instruments, such as the reactor period meter and the linear level channel are fed into the CSAs. All scram trip signals must pass through CSAs to affect the scram. Thus, replacement of the CSAs with integrated solid-state devices has been the highest priority task. There are a number of advantages with the integrated solid-state devices in particular; longevity, reliability, procurement, maintenance, and direct PC interface capability.

4. PROJECT DESCRIPTION

4.1 Convert the Control and Safety Amplifiers (CSAs) to Solid State Electronics

As stated earlier the electronics of the CSA's consists of 1950's vacuum tube technology and there is lack of availability of replacement parts and repairs. The vacuum tube electronics is based on a high voltage system (~120 volts DC), and signal outputs are not available. Thus, these units cannot be easily interfaced to computer (PC) based data acquisition systems and display. It should be noted that the CSAs are the key safety system of the reactor. They control the magnet currents for the shim safety rods. The trip signals from all other instruments, such as the reactor period meter and the linear level channel are fed into the CSAs. All scram trip signals must pass through the CSAs to effect the scram. Thus, replacement of the CSAs with integrated solid-state devices has been the highest priority task.

This phase of the work has been funded through URI program for FY 1999-2000.

Status:

Initial implementation of this project is complete. A progress report was issued to DOE for this phase of the work. This Safety Monitor Chassis constructed by the Phillips Electric Corp. at Cleveland Ohio has been received.

4.2 Upgrade and Replacement of Instrumentation Chassis and Radiation Monitor

This phase of the work has been funded through URI program for FY 2000-2001. Implementation of this project is under progress. The plan for the FY 2000-2001 was to continue upgrading the instrumentation chassis. This required purchasing a compensated ionization chamber for channel three, the linear channel. The current system is an uncompensated BF3

detector, and so the accuracy of the linear output is hampered by the fission fragment's gamma production when the reactor power is on a negative period.

Status:

- (1) Replace three old radiation area monitors with new monitors: Area Monitors are received from vendor and have been installed. Procedures for installation and calibration have been completed.
- (2) Replace one old continuous air monitor with new monitor: This Monitor is received from vendor and has been installed. Procedures for installation and calibration are under progress.
- (3) Add four new high deflection angle meters as display meters for the console: There was a problem in procurement of this item from the vendor. Vendor did not supply the equipment in spite of number of requests and the budget period was run out and hence could not purchase the equipment from the DOE budget. School has agreed to buy this equipment from internal funding.
- (4) Add one personal computer based data acquisition and display system: Equipment received installation under progress
- (5) Replace the uncompensated BF_3 detector with a new compensated ionization chamber for channel three, the linear channel: Equipment received installation under progress

For project items (4) and (5), a senior undergraduate design project has been planned where students will work in the design project involving installation and calibration process.

4.3 Upgrade of Channel Three and Interface for Channel Four

Description and use of the Linear Reactor Level (Channel 3)

Of the four detector channels for control of the PUR-1 reactor, channel three is the only one with a linear output to the console. This allows the operator to see changes in neutron flux levels on a finer scale than would be possible with the log output from the other instrumentation

channels. It also allows for teaching demonstrations of the reactor condition, such as critical vs. source critical, prompt jump and drop, subcritical leveling off vs. criticality, etc.

Channel three consists of a BF₃ gas filled ionization chamber, operating in current mode, coupled to a wide range micro-micro-ammeter (or pico-ammeter). This ammeter can accurately read current down to the order of 10E-13 Amps. It has manually changeable range switch. The ionization caused in the detector, and hence the current output, will be proportional to the neutron flux within the reactor. The ammeter translates this current directly into visual information via meters on the console and the instrumentation chassis, and a strip chart recorder that the operator can view. The adjustable range switch allows the linear channel to be on range over the entire spectrum of reactor operation from shutdown to full power.

The linear channel is also the input signal for the flux controller, or servomechanism. While the flux controller hardware is physically located within the chart recorder unit for channel three, it uses the linear channel to maintain the reactor power at an operator determined level. The servomechanism is tied into the regulating rod drive motor to allow adjustment of the reactor level as needed.

This channel is required to be operational and on range during all reactor operations. To ensure this, the output of the channel three detectors is coupled into the setback and scram circuitry. If the operator fails to keep the range switch on an appropriate setting (e.g., between 0 and 110% of the meter scale) the setback mechanism is triggered and the control rods drive back into the reactor. Additionally, if the operator allows the meter reading to approach 120% of the scale, a scram is initiated and the two borated control rods drop into the core.

Equipment comprising the linear channel

Channel three, as stated above consists of a neutron sensitive gas ionization detector, an

ammeter to read the output current of the detector, and output meters and recorders for the operator. Additionally, the electronics package must contain a high voltage power supply for the detector, connections for electronic maintenance and calibrations, and appropriate output lines to operate the console and chassis meters, the strip chart recorder, the flux controller, and to signal setback and scram conditions.

Justification for new equipment

The current equipment for channel three dates to the late 1950's. The micro-micro-ammeter, though still functioning properly, is designed with vacuum tube technology. The electronics are very old, and purchasing replacement parts will soon be not only prohibitively expensive, but also very nearly impossible. Additionally, the electronics expertise necessary to repair and adjust vacuum tube systems is a diminishing resource. In addition, as part of our program to upgrade the PUR-1 instrumentation, we have selected a compensated ionization chamber (CIC) to replace the existing non-compensated BF3 detector. The CIC requires a different high voltage than the previous detector and will require a second power supply for the gamma compensation current.

Description of the Instrument

It is proposed to purchase a system from Circuit Equipment Corporation that will be built to satisfy our requirements. It will be a pico-ammeter capable of reading the CIC during reactor shutdown with the source in. To help maintain the teaching capability of the linear channel, it will have manually adjustable range switches, but of a push button type to both eliminate the possibility of two switches at once and reduce the probability of moving the range the wrong direction. The necessary internal relays and external outputs will be provided to allow the new chassis to integrate with the existing meters, recorders, scram circuits, console, etc, and to then

connect with the new equipment that has been and will be purchased as part of this upgrade.

Status:

(1) Install a micro-micro-ammeter capable of reading compensated ionization chamber during reactor shutdown with source in: The funding has been awarded for this equipment project. Order for procurement of this equipment is under progress.

Channel Four Interface

The Electronics Chassis for what at the Purdue Reactor is called Channel-4 or the "Safety Channel". Channel-4 is key chassis in our replacement and upgrade plan. This upgrade of channel 4 was begun with phase 1, which has been funded under URI program for FY 1999-2000.

PUR-1 has two safety rods. Each safety rod has an electromagnet so that the rod may be quickly dropped during what is referred to as a "scram". Channel-4 currently controls both of these electromagnets and is housed in two 19 X 8 ½ inch relay type chassis called Control and Safety Amplifiers or CSAs. As they are currently configured CSA-1 is a linear power monitor with its own independent detector, which, scrams (i.e., drops) both rods electronically (i.e., with active components not with relays) at less than 120% power. This electronic scram is called a "fast scram" in our technical literature. The other chassis CSA-2 receives a signal (in the form of a voltage) related to the power level of the Reactor from Channel-2 (Log and period detector/amp channel). CSA-2 converts any changes in this signal to a "rate of change signal" called period. CSA-2 will "fast scram" (electronically) both rods before a 7-second period is reached. A relay and key switch system currently cuts the 120vac power to both of the magnet power supplies thus assuring that both rods will drop. Each CSA chassis has two power supplies. One is independent and used only to supply magnet current.

The current plan was to replace every chassis and ultimately interface electronics to a data acquisition system (computer). This Safety Monitor Chassis was constructed by the Phillips Electric Corp. at Cleveland Ohio. The current request was to design and install the cards to interface from the Channel Four detector, and the Channel Two period output so that this the rods may be dropped as power and or period are increased as required in per PUR-1 Technical Specifications. And as a future or concurrent project to have boards designed so that they will annunciate any failure within this chassis and interface smoothly to the rod drop magnets via connectors and the outside world via one 25-pin computer connector

Table 2 lists the projects considered under this proposal along with equipment and service.

Table 2. List of Project and Equipment Required

<i>Project</i>	<i>Equipment</i>	<i>Service</i>
(1) Interface PUR-1 Channel four to the power control system	Sixteen interface cards (Purdue staff will manufacture these circuit cards)	Reactor Staff will perform installation and testing

5. PROJECT STATUS

The following highlights the status and the progress achieved on the project that utilized the funding from the DOE-URI grant program.

1. All the requirement components for the 'Safety Monitor' were ordered.
2. Eight cards were designed with CAD. Typical circuit layout is shown in Figure 1.
3. The printed circuits were manufactured with local vendor. Typical printed circuit is shown in Figure 2.
4. These boards were then installed with eyelet and edge connector as shown in Figure 3.
5. The 'box' that will comprise our final chassis has been fabricated as shown in Figure 4.

The new box will replace the two chassis shown in Figure 5.

Remaining tasks on this project are:

Circuit card hand assembly, Chassis machining for connectors and mounting, Chassis wiring harness, Bench test and test documentation, Documentation of all, including parts and circuit functions, Writing of installation procedures, Documentation of Title 10 Code of Federal Regulations part 50.59 (10CFR50.59) compliance, Installation into existing system and Testing during reactor operations.

Figure 1. Circuit card layout.

Figure 2. Typical circuit board received and the plated through

Figure 3. Eyelets installed and the edge connector installed.

Figure 4. Fabricated box, which will house the new circuits.

Figure 5. The two chassis to be replace by the new chassis