An Educational Platform for Modern Instrumentation and Control of Nuclear Systems

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1 Project Objectives

We propose to establish the infrastructure for an educational platform that will attract and instruct students in modern nuclear instrumentation and control (I & C) methods to serve the nuclear power fleet, laboratories in the DOE complex, and technology based industries for the next generation. The emphasis will be on the use of real time digital instrumentation in both an educational and research environment. Our objective will be to use the support from this proposal to construct five instrumentation stations and one end station for a high neutron fluence based research program containing the digital technologies used in national research laboratories and industry. We intend to expose student to radiation damage studies using the end station which are relevant for the NEUP's advanced fuel initiatives. According to the IAEA, about 40% of the worlds operating nuclear reactors have modernized their analog based instrumentation and control systems with digital technology. We believe our proposal will establish a practical modern instrumentation training facility in support of the NEUP's mission to further NS&E R&D and education.

1.1 ISU's NS&E program

Idaho State University has a wide breadth nuclear science and engineering program encompassing disciplines in health physics, nuclear engineering, and fundamental nuclear physics. Idaho State University's Health Physics program is housed in the Nuclear Engineering department and offers graduate degrees as well as an ABET accredited Bachelor of Science degree in Health Physics. The Nuclear Engineering department offers an ABET accredited Bachelors of Science degree and houses a training and research nuclear reactor (AGN-201). An applied nuclear physics facility, known as the Idaho Accelerator Center (IAC), has an established research record in areas ranging from the radiochemistry of medical isotope production to nuclear physics applications addressing homeland security issues in cooperation with the Idaho National Laboratory (INL). ISU's NS&E program has over twenty faculty and fifty students working in the Nuclear arena.

1.2 Proposal's Impacts on NS&E, R&D and Education

ISU's NS&E program and the nuclear fleet share the same need for equipment modernization. ISU's current program has been providing students with an opportunity to be trained and work with instrumentation commonly used by the nuclear work force. For more than five years, a joint continuing education program between ISU and the Idaho National Lab has been working to transfer knowledge to their nuclear work force from ISU. We propose to take the next step in this knowledge transfer by creating a modern instrumentation laboratory and end station to educate students, pooled from ISU's NS&E programs as well as INL's nuclear work force, with instrumentation and control (I & C) skill sets that support the nation's intellectual dependence on Nuclear Engineering and Nuclear Science. In addition to adding a practical training element to the continuing education program between ISU and the Idaho National laboratory, the modern instrumentation laboratory can facilitate the exchange of knowledge between current members of the work force and those seeking to enter it.

1.3 Equipment Use goals

The equipment acquired through this proposal will be used to establish five digital instrumentation stations, similar to a station in current use shown in Figure 1, that are used to perform five separate measurements using five different instruments. One laboratory will calibrate and use a high purity Germanium (HpGE) detector to identify the nuclei in given activated multi-element samples using gamma spectroscopy. A second laboratory will make measurements using a long neutron sensitive scintillator to determine the position dependence of a source along the scintillator based on signal flight times to PMTs attached to both ends of the scintillator. A third experiment will measure the properties of an ionization chamber signal as a function of applied voltage exploring one of the fundamental instruments used in the field, the Geiger Muller tube. A fourth experiment will measure the detection properties of a custom solid state detector that has been made sensitive to neutrons by radiation damage. The final experiment will use a fission chamber purchased from General Electric in both the classroom station and under the high neutron fluence rates at the proposed end station. The final experiment will also introduce student to pulse shape discrimination of photons and neutrons using a flash ADC. The PIs will devote their curriculum development time towards installing the equipment, writing manuals for the above experiments, and commissioning the stations for use by students.

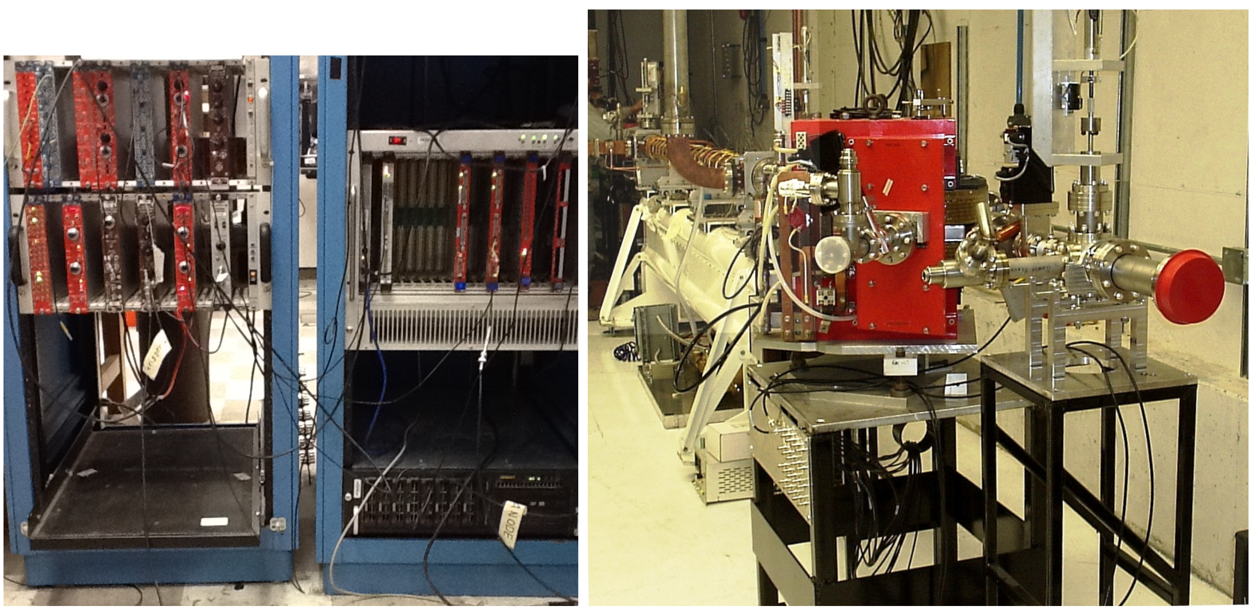

Figure 1: Pictures of the current VME based data acquisition system (left) and the electron accelerator capable of 50 MeV electron energies (right).

A high neutron fluence end station will be constructed using an 50 MeV electron beam and a high Z converter material (Tungsten). Figure 2 contains a conceptual drawing of the collimator with a heat exchanger cooling system wrapped around the Tungsten cylinder. The Tungsten converter will be machined from a solid Tungsten cylinder and have channels off the central axis for the purpose of positioning detectors or materials to be radiation damaged. We expect the end station can contribute to research in the NEUP's advanced fuel initiative program. The converter target will be mounted on a custom stainless steel carrier capable of supporting part of the requested shielding. An electron beam accelerated to energies up to 50 MeV and capable of depositing up to 12 kW of power into the target cell will be used to generate neutrons. A simulation predicting the expected neutron fluence from the proposed system is shown in Figure 2.

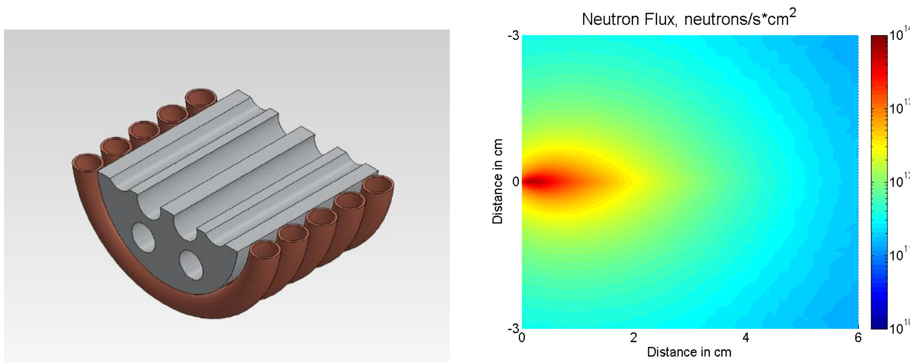

Figure 2: Left: A cross sectional slice of the Tungsten collimator conceptual design. Right: Neutron fluence predictions using MCNPX assuming a 10 kW electron beam on a Tungsten converter.

2 Merit Review Criteria

a) The creation of a modern instrumentation and controls laboratory will substantially expand the research and training capabilities of ISU's NS&E program. The skills learned can easily be transferred to the testing and training reactor facility operated by the Nuclear Engineering department. However the most aggressive expansion will be in the creation of an accelerator driven high neutron fluence facility. This proposal will provide the end station equipment as well as test cell that will allow an existing accelerator located at the IAC to become a high fluence neutron source for both research and education. This end station will be equipped with a fission chamber that is currently used for "in the core" measurements of neutron fluence in the nuclear industry. The commissioning of this facility will open the door to further research in neutron flux detector development as well as materials studies.

(b) While the twenty faculty serving ISU's current NS&E programs provide a wide breadth of intellectual support for the proposed modern instrumentation laboratory and end station facility, the core personnel responsible for project execution have expertise in data acquisition and accelerator driven systems. The PI has more than five years of experience with the digital acquisition systems used in intermediate nuclear energy national physics laboratories and has installed identical systems in his research laboratory. The Co-PI has spent the last two years configuring and operating an accelerator based radio isotope end station. The Co-PI will transfer those experiences to the development of a high neutron fluence end station that is also accelerator driven in cooperation with accelerator physicists at the Idaho Accelerator Center. Two other faculty members will develop the experiments to be performed at the five training stations in the digital instrumentation and controls laboratory.

(c) We anticipate that the digital instrumentation and control laboratory will become the second in a series of laboratories to train students in nuclear instrumentation and control. A current instrumentation lab trains students on the operating principles of detectors and uses analog signal processing to drive counters to quantify the activity of radioactive sources. This “analog” instrumentation laboratory has been taught by faculty from the Nuclear Physics and Health Physics programs for more than five years. More than 10 students have been taking the class each time it is offered. We anticipate at least five of those students would continue their education and enroll in the “digital” instrumentation and controls laboratory.

(d) The digital instrumentation and control laboratory will be equipped with several modern electronics modules to facilitate the objective of this proposal. The ISU physics department currently has five VME based crates that are used to house digital modules for processing analog input signals to a digital format that is available through the back plane of the VME crate. The physics department has recently purchased five modern micro-controllers for the VME crates which use the latest intel processors to control and transfer data from digital modules in the VME crate. We would like to continue the modernization by purchasing another VME system for a research based station as well as several digital modules for all six VME systems. The Idaho Accelerator Center has recently deployed a new linac in a heavily shielded room with a high current for medical isotope production. We propose adding a target system to this facility optimized to produce a neutron fluence of at least $10^{13} n/sec/cm^2$.

3 Project Time Table

The support structure for this funding opportunity asks for a performance period that ends within one year of the award date. All digital equipment purchase orders will be issued within the first three months of the award. Custom equipment will be under contract with the appropriate vendor within the first six months of the award. Installation of all digital equipment is expected to be complete nine months after the award. Commission of all digital instrumentation stations will be completed at the end of the first year and the high fluence neutron end station target will be installed.

*Months after award is received.

Month*	Objective
3	Complete equipment purchase order for equipment
6	Conclude custom equipment procurement contracts
9	Complete digital equipment installation and begin commissioning
12	Complete digital equipment commissioning and high power target installation

Table 1: Work Plan Timeline

Participant	Role
Dr. T. Forest	Order and install equipment and prepare laboratory manuals
Dr. V. Staravoitova	Supervise design and construction of a high power target
Dr. D. Dale	Commission equipment and prepare laboratory manuals
Dr. D. McNulty	Commission equipment and prepare laboratory manuals

Table 2: Participant Roles in Project

4 Roles of Participants

5 Facilities and Other Resources

The PIs have created a Laboratory for Detector Science at Idaho State University which houses the group's infrastructure for detector development projects. The 1200 sq. ft. laboratory is equipped with flow hoods, a darkroom, and a laminar flow hood used to provide a clean room environment sufficient to construct small prototype detectors. A CODA based data acquisition system with ADC, TDC, and scaler VME modules has been installed to record detector performance measurements. The PIs also established a student machine shop containing a mill, a lathe, drill press, table saw, and band saw which occupies its own space for the physics department to share. A 400 sq. ft., class 10,000 clean room has been constructed in ISU's physics department. These facilities have a history of being used to construct detectors, measure detector prototype performance, and design electronic circuits.

The Idaho Accelerator Center (IAC) is located less than a mile away from campus and has ten operating accelerators as well as a machine and electronics shop with a permanent staff of eight Ph.D.s and six engineers. Among its many accelerator systems, the center houses a linac capable of delivering average electron beam currents of 250 μA at energies up to 40 MeV (unloaded). As shown in Figure 1, the accelerator has been constructed and is currently entering its commissioning phase. We propose constructing a 10 kW target cell at the end of this beam line capable of producing a neutron fluence of 10^{13} n/s/cm^2. A full description of the facility is available at the web site (www.iac.isu.edu).

6 Equipment

The proposed digital instrumentation laboratory and end station will be based on a VME (Versa Module Europa; IEEE 1014) bus system with a single board computer to control digitization modules and data transfers. The VME bus with a computer controller is one of several widely used standards for controlling distributed devices on a network (Iterbus-S). We believe this system will be a good introduction to a decentralized architecture for the student. Each station will have one VME crate with an Intel based controller made by GE (GE XVB601). Each station will also require a discriminator and a two channel gate delay generator to form a digital trigger pulse for the data acquisition system. Three laboratory stations will need a standard ADC and one will need a flash ADC for pulse shape discrimination. Three stations will require post amplifier NIM modules and one will need a TDC for time of flight measurements. The cost and quantity of these modules as well as the costs of addition infrastructure for their use is listed in the Budget table.

We also propose the construction of a target cell and chamber to be used with an electron accelerator for the purpose of producing a neutron fluence of $10^{13} neutrons/sec/cm^2$. An MCNPX simulation predicts that, for electrons in the energy range of 40-50 MeV, a cylindrical target should have a minimum radius of $\tilde{3}$ cm and a length of at least $\tilde{6}$cm. The surfaces of constant neutron flux are ellipsoids distributed about the cylinder's central axis. Narrow sample cavities (tubes) are arranged around and parallel to the central axis much like a revolver pistol, see Figure 2. This accelerator neutron source approach was chosen based on a cost effective study which indicated it would be about a factor of five less expensive than spallation sources, particularly at a neutron fluence of $10^{16} n/s/cm^2$ [1]

7 Utilization

The proposed digital instrumentation laboratory will be a training platform for students and the additional end station can provide opportunities for both students and faculty research in the nuclear arena. Based on the demand experienced with the analog instrumentation laboratory, we expect at least five students to enroll in each class. We also expect the high neutron fluence end station to receive considerable use as both a research and training vehicle. We expect at least two experiments per year will be performed at the facility with the potential for publication in refereed journals. When fully commissioned the end station facility would be available for outside users.

References

[1] H. Safa, EURISOL Target Working Group Meeting, Saclay, May 21, 2001