Applied Nuclear Physics at JMU

Overview

Nuclear science and technology is a critical area for the development of the nation in the 21st Century and beyond: safe nuclear fuel will lessen the dependence on foreign oil, while nuclear medicine will continue to provide advanced diagnostics and disease treatments. Sampling and nuclear measurement techniques help safeguard the environment and enhance the security of the homeland in this era of reshaped global threats. Maintaining the United States’s leadership in science and technology requires an enduring vigilance on science education, particularly in nuclear physics education. While the overall percentages of students, including women and historically underrepresented minorities, attending and graduating from college are rising the number of students focusing in science, math, and technology areas continue to decline.

The paucity and manner in which nuclear science topics are present in the undergraduate curriculum seriously hampers efforts to recruit the next generation of nuclear scientists, engineers, and technology-savvy policy makers. A recent survey reveals that only about 18% of the larger physics departments in the U.S. offer nuclear physics classes, with another 20% of the universities offering combined nuclear/atomic/particle physics classes. These numbers become significantly worse if one considers only classes that have an experiential, laboratory-based component focused on undergraduates.

The Department of Physics and Astronomy is developing a new track in the applied physics concentration to address this need. This document outlines the proposed program and how it incorporates a linear accelerator, a very rare component in undergraduate education, as central component. The impact of this instrument on the scope and quality of our teaching and research is significant. Requested here is the particular space on campus that is uniquely suited to house this program.

The Applied Nuclear Physics Track

The applied nuclear physics track requires the development of three new courses: a lecture and two laboratories. Combining these with existing nuclear and particle physics courses and Chemistry 450/450L, Nuclear and Radiation Chemistry, forms the core of a nuclear curriculum with a breadth and depth rare in any undergraduate program. Providing a comprehensive range of hands-on experiences for our students is central to this program. To build the students skills in the operation of alpha, beta and gamma detection a diverse array of detectors, electronics and radiation sources are required. To fund the acquisition of these resources, a Letter of Intent has been submitted to the U.S. Nuclear Regulatory Commissions Nuclear Education Grant Program for detectors and electronics costing $166,153.

To expand our nuclear science program, the faculty will develop three new classes to be offered to our students beginning in the 2008-2009 academic year:

1. Basics of Applied Nuclear Physics. This class provides a solid foundation for experimental work in applied nuclear physics by introducing the basic concepts of radioactive decays, radiation transport and interaction with matter, basics of radiation detection devices, and dosimetry. This class will be offered at the 200 level, aimed primarily at sophomores and juniors. The class will emphasize the practical applications and challenges specific to radiation use and the designing, building, and operation of radiation detectors.

2. Applied Nuclear Physics Laboratory (I). In this laboratory class the students will learn the operation of alpha, beta, and gamma radiation detectors, the associated electronics and data/analysis acquisition systems. They will measure the activity and lifetime of radioactive nuclides, as well as perform basic dosimetry measurements.

3. Applied Nuclear Physics Laboratory (II). In this advanced laboratory (reserved for seniors and outstanding juniors) the students will study more sophisticated nuclear physics techniques, including soft γ and X-ray spectroscopy, coincidence/anticoincidence measurements, isotope identification, non-destructive analysis of materials, basics of PET tomography, analysis of solid and liquid medium samples (in the lab and in situ).
inserting metal foils in the electron beam. These energies can allow excitation of the low-lying nuclear spectrum throughout much of the periodic table.

This energy range is ideal not only for introducing students to the issues of dosimetry associated with such a facility, but also characterization and development of a wide variety of detector systems. Our nuclear physics faculty are pursing research programs Jefferson Lab and Duke University that use electron and photon beams (and other programs at the Paul Scherrer Institute Switzerland and at FermiLab in Illinois). The addition of an on-campus facility at which we can train students and develop instrumentation will significantly impact our ability to give our students more meaningful experiences at the larger, off-campus labs.

Since this device is designed for patient irradiation, the beam can be directed in any direction in a plane as the gantry rotates about a horizontal axis. This can be seen in figure 1. This capability is ideal for the development and calibration of detectors that have a fixed orientation or geometry. The ability to characterize the response of detector to such a wide range in electrons or photons without the need for expensive and dangerous radioactive sources is vital if we are to continue the expansion of our nuclear physics research program and adequately prepare our students.

However, this versatility also means that shielding must be in place for not only secondary radiation but for the primary beam in all directions. Because this beam is capable of producing nucleon emission, in particular neutrons, and

All classes will devote 20-25% of their time to computer modeling of radiation transport and detection, during which students will use/develop increasingly sophisticated simulation codes. All supporting materials instructional and safety manuals, and software - will be developed by JMU physics faculty.

A key component in this program is our ability to give our students experience, not only with radioactive sources, but also with electron and photon beams. In the fall of 2006, Rockingham Memorial Hospital donated to the university a linear accelerator (linac). With this device, we can provide our students a full range of experiences in nuclear physics and prepare them for graduate school in nuclear or particle physics, nuclear engineering or medical physics as well as for directly entering the workforce in the nuclear industry or government.

**The Linear Accelerator**

The linac was designed for the irradiation of patients with a variety of diseases. This machine can provide electron beams with energies in several steps up to 15 MeV and a photon (\(\gamma\)-ray) beam in several steps up to about 12 MeV by inserting metal foils in the electron beam. These energies can provide nucleon emission in many nuclei and allow excitation of the low-lying nuclear spectrum throughout much of the periodic table.

![Figure 2: The attenuation of 1.3 MeV \(\gamma\)-rays in high density concrete. This is data obtained by the National Research Council (NRC).](image)
directly produces $\gamma$-rays, careful shielding is required. As shown in figure 2, the 1.3 MeV $\gamma$-rays from $^{60}$Co require substantial shielding using high density concrete and this machine is capable of producing photons with 10 times this energy. The secondary neutrons fill the accelerator room just as a gas fills a box. This radiation also requires substantial shielding to ensure personnel safety. This is shown in figure 3. It is clear that substantial shielding is required to make a safe environment for operating such an accelerator usually four or more feet of high density concrete.

Finally, the presence of this ionizing radiation produces ozone. This requires that the air handling system be capable of changing the volume of air in the room 10 times per hour to maintain safe levels.

It is primarily these requirements that make finding a suitable place to safely operate the linac expensive. We have investigated the construction of a simple rectangular building on campus made from a sufficient thickness of high density concrete to house the machine. Excluding the air handling system, the wiring and plumbing for power and water needs, and space for support activities, we estimate it to cost in excess of $1M merely for the high density concrete. Even if we elect to build such a building, there is an extensive and expensive review process required by the Nuclear Regulatory Commission to ensure that the new building meets all state and federal regulations and guidelines for the operation of such an accelerator.

Much of this expense and paperwork is avoided by simply using the facilities in the Cancer Center at 100 Grace Street where it has already safely and legally operated. When the hospital moves to their new facilities, the linac they purchased to replace the one we have will be moved. However, the Cancer Center operates two linacs. The older one not yet replaced will be replaced at the time of the move. Thus, we expect that this second linac will also be donated to the university. The location of the applied nuclear physics program in these existing facilities means that this second machine will be available for no costs associated with moving, storage, or re-installation.

**Space Requirements**

We propose to house the entire Applied Nuclear Physics program at the Cancer Center. This will require office space, shop and laboratory space in addition to the rooms housing the linac(s). Because the establishment of this program represents a significant investment in electronics, we are requesting (in a separate budget initiative) an electronics technician with an office and an electronics shop. To use the linac, space outside the accelerator vault is required in which to place the electronics and readout computers. In this data acquisition area, students and faculty can safely work while the beam is on to set up and perform measurements. In addition, some space is required for experiment preparation, the storage of low-level radioactive sources (used for system checks and calibrations), equipment storage, and for a teaching laboratory. The area of the Cancer Center in which we request space to house this program is on the east end of the ground floor, as seen in figure 4.

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**Figure 3:** The attenuation of neutrons in high density concrete. This is data obtained by the National Research Council (NRC).
Figure 4: A plan view of the ground floor of the Cancer Center at 100 Grace Street. The portion of the building being requested is on the east end of the building (bottom in the figure).
The portion of the Cancer Center being requested to support this program is indicated in figure 5. The numbered areas show the space requested to house the linac(s), personnel, teaching labs and permit safe and effective use of the instrumentation. Referencing the labeled areas in figure 5, the spaces requested will be used as follows:

1. This area will be used as a teaching laboratory for the Applied Nuclear Physics Laboratories, described
above. There is no space in the Physics and Chemistry building to dedicate to this laboratory. Having this space will avoid the need for equipment storage, the sizeable recovery time investment each time it is moved, and provide greater flexibility in scheduling as the program grows.

2. This area will be dedicated to the data acquisition electronics and a data analysis computer laboratory for the linac(s). Once the experiments are configured in the shielded rooms (area 5), students and faculty can safely work in this area to collect and analyze data. Since much of the data acquisition electronics and instrumentation are the same from experiment to experiment, having a dedicated space for this is essential.

3. Because nuclear physics uses extensive electronics, this area is requested for use as an electronics shop. Here, equipment will be tested, repaired and constructed for the program. Since many of our students are taking electronics courses in our department and are contributing to the development of specialized electronics equipment in our research programs, we anticipate students will also work in this space with the technician, gaining further experience valuable for entry into graduate school and industry.

4. Office space is also requested to house the electronics technician that is necessary for the success of this program. Additional office space is also requested for faculty offices to permit growth of the program and to allow faculty with offices on east campus to also use space in this facility while teaching here.

5. This is the highly shielded space to house the linac we currently have in storage (bottom room) and the linac we expect to obtain from the Cancer Center when they move (middle room). The smaller shielded room at the top will be used as a space to setup long term research projects with radioactive sources, some of which may be higher intensity than the typical calibration sources.

This space is requested not just to insure physical proximity of the component laboratories, but also because there is no space for these activities in the Physics and Chemistry Building and the space to house the linac is unique. While we plan to implement this program before the Grace Street facility become available, we cannot accommodate more than a few students and the scope of the teaching and research activities are limited.

It is important to stress that this space will support an integration of teaching and research in nuclear physics that is, with existing facilities, not been possible. Having space in which to set-up long-term research projects without interfering with class access and using the same facilities for both teaching and research is central to the successful combination of these two aspects of our vision.

Program Summary and Impact

The initiation of the Applied Nuclear Physics program will be accomplished using external funding. As noted above, this money is being sought from the Nuclear Regulatory Commission. Nevertheless, no money is requested in this space proposal to support the linac and the technical personnel needed to maintain and operate it. This is because the new laboratory experiences will be assembled in stages. While we wait for the availability for the Cancer Center space, the laboratories using radioactive sources will be designed and taught in the existing teaching and research laboratory space in the Physics and Chemistry Building. A budget initiative has been submitted requesting a new staff position in the department to support nuclear physics and astronomy so that once the space is available we have the manpower to bring the facility on-line. The delay of a few years is useful to allow us to start up the program in a manageable way. It is possible that additional external funding will be sought to support the re-installation of the linac when required. It is assumed that the remodeling needs can be included as part of the renovation of the entire building.

Once installed and fully operational, this facility will provide our undergraduates with opportunities that are rare in any physics department in the country. The handful of research universities in the US that operate accelerators all maintain them for research for graduate students, postdocs, and faculty, with undergraduates playing a minor, support role, if any. Activities at our facility will be focused directly on teaching and providing experience for undergraduates. There are very few undergraduate physics departments that have accelerator facilities. For example, Hope College has an accelerator for producing beams of protons and alpha particles and Taylor University has a linac similar to ours. This facility will put the JMU Department of Physics and Astronomy among a very select few undergraduate programs in the country. With the
acquisition of a second linac when the hospital moves, JMU will be uniquely equipped to integrate teaching and research at the highest level.

The accelerator laboratory will form an integral part of our teaching and research efforts. Because the nuclear/particle physics research in our department requires the use of large facilities at national laboratories and research universities, on-campus access to an electron or photon beam on campus will permit our students to learn not only about accelerator operations but engage in the calibration of detectors for use at the larger facilities. This is a capability that is limited to a few radioactive sources at present. This means that many tests for many detector types simply cannot be done. We expect that the addition of this capability will open many new opportunities for our faculty to obtain external support for our students.

Our students will graduate with strong foundations in radiation detection, the use of radioactive sources and in-beam studies. These skills and the foundation we will provide in applied and fundamental nuclear physics will open doors to underserved areas in environmental studies, medicine, engineering, and physics. This broad array of skills, coupled with our astronomy and material science programs will give our students an unprecedented range of opportunities that are truly unique at an undergraduate institution.