Multidisciplinary Engagement at Research Reactors: The NCSU PULSTAR

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Abstract. The PULSTAR reactor at North Carolina State University (NCSU) is the primary facility of the Nuclear Reactor Program; a Board of Governor's Center in the University of North Carolina system. It went critical in 1972 and has been operating at 1-MWth for the past 45 years. To enhance the engagement of the PULSTAR in the institutional mission of NCSU, a strategic plan with well-defined education, research and service/outreach objectives has been under implementation for the past 15 years. Educationally, this included pioneering modern modalities such as the Internet Reactor Laboratory (IRL), which is currently in its 12th year of implementation with international extensions to Jordan, Vietnam and other potential regions. In scientific research, several unique and high-performance instruments have been developed and operated including a neutron powder diffractometer, an intense positron beam, an advanced neutron imaging system, an ultracold neutron source, and a fission gas release and measurement loop. These instruments are currently utilized to address the needs of a multidisciplinary community of fundamental and applied researchers. In addition, projects supporting the nuclear data community and emerging fields such as cybersecurity have been launched. Furthermore, the engagement footprint of the PULSTAR is highly enhanced through national and industrial partnerships to support developments in important sectors such as nuclear energy, nanotechnology and radioisotope production. This includes memberships in two important consortia: the US Department of Energy's Nuclear Science User Facilities (NSUF), and the US National Science Foundation's Research Triangle Nanotechnology Network (RTNN). The combination of capabilities and partnerships has resulted in significantly enhancing the utilization levels of the PULSTAR to approach 10,000 user hours annually. Consequently, over the past 15 years the PULSTAR has succeeded in meeting or exceeding institutional metrics for educational impact, multidisciplinary engagement, academic/scientific performance, and the ability to be self-supporting. This trend is expected to continue as the PULSTAR upgrades to a power of 2-MWth and completes the implementation of its next generation of instruments and projects.

1. Introduction

Research reactors, especially at university campuses, are frequently expected to meet institutional metrics to continue being considered "viable" entities. These metrics may differ somewhat from one institution to another, but in general include fulfilling set financial and utilization objectives. Furthermore, for some institutions the specifics of how the objectives are met may be relevant. In that case, engagement of the reactor in nationally and internationally recognized education and scientific activities proves important. The importance of these considerations becomes clear upon inspecting the trending numbers of research reactors in the United States (see Fig. 1 below). As it can be seen, the number of research reactors has decreased for a high of 66 reactors in the 1970s to the current number of 24 reactors. Moreover, several reactors on the campuses of major universities that are well known for their strong science and engineering programs (including nuclear engineering) have been shut down and decommissioned. In some cases, the decision to shut down the facility was made despite the fact that it was financially healthy, which corroborates the view that the success of a research reactor at a university is an institutionally dependent multifaceted endeavor. Consequently, the potential success of a given research reactor facility must be carefully analyzed in view of the institutional peculiarities. The outcome of this analysis should be a realistic strategic plan that is implementable using tangible milestones that meet short and long term institutional metrics.

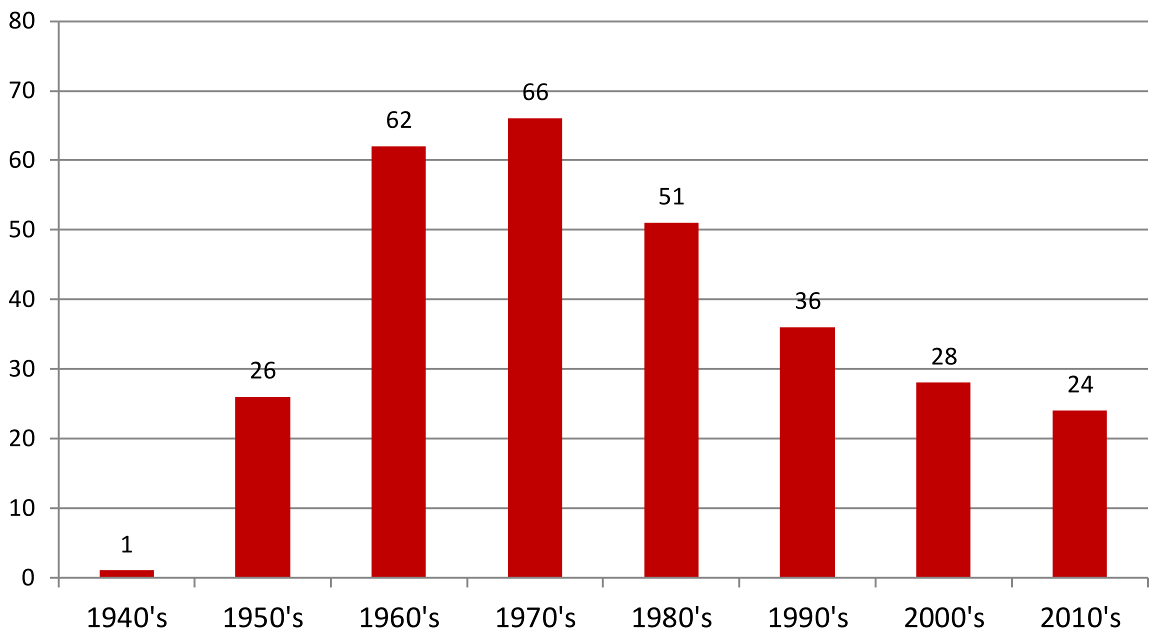

FIG. 1. The number of university research reactors in the United States (data derived from Ref. 1).

A key aspect in meeting the performance metrics for a research reactor on a university campus is its multidisciplinary appeal. Considering that many such reactors represent intense radiation sources, the implementation of a multidisciplinary strategic plan would seem intuitive in view of the various radiation probing and testing capabilities that the reactor would be able to provide for on and off campus users. However, many institutions tend to emphasize the detailed breakdown of this utilization to ensure that the reactor remains relevant to the institutional mission.

2. The PULSTAR Research Reactor

The PULSTAR reactor at North Carolina State University (NCSU) is housed within the Nuclear Reactor Program (NRP), which is a Board of Governor's Center of the University of North Carolina System. The PULSTAR can be considered a representative research reactor facility. It currently operates at a power of 1-MWth and is awaiting approval by the US Nuclear Regulatory Commission (NRC) to initiate operations at 2-MWth [2]. The PULSTAR went critical in 1972 and for 44 years operated using a core of uranium dioxide (UO_2) fuel enriched to 4% in U-235. Recently, it was awarded US NRC approval to begin operating using a mixed core of 4% and 6% enrichment in U-235 [3,4]. This assured the ability of the PULSTAR to use local fuel reserves to secure its operation until the mid 2020s.

Surrounding its core, the PULSTAR has 6 beam tubes that have been developed over the past 15 years to drive various irradiation facilities for the examination and testing of materials. This includes, a neutron powder diffraction facility located at beam tube 4, a neutron radiography facility at beam tube 5, an intense positron beam facility located at beam tube 6, a fuel testing facility located at beam tube 1, and an ultracold neutron source located in the original thermal column cavity [5-9]. In addition, the reactor is equipped with a pneumatic irradiation system that is primarily used to support neutron activation analysis experiments, and with various irradiation locations that are located in the vicinity of the core and are used to drive testing experiments for various users. As might be expected, the development of all these facilities is influenced by logistical and technical aspects that include the specifics of the radiation environment provided in and around the core of the PULSTAR. In this case, the PULSTAR's core is characterized by a highly under moderated design that results in the thermal neutron flux peaking around the core. Figure 2 below shows a layout of the PULSTAR core with the different irradiation locations and a representation of the neutron flux energy distribution in and around the core. This spatial and energy distribution of neutrons has proven of great utility to the development and utilization of all PULSTAR facilities as it optimizes the thermal neutron flux at the entrance of beam tubes and at the irradiation locations of the different facilities.

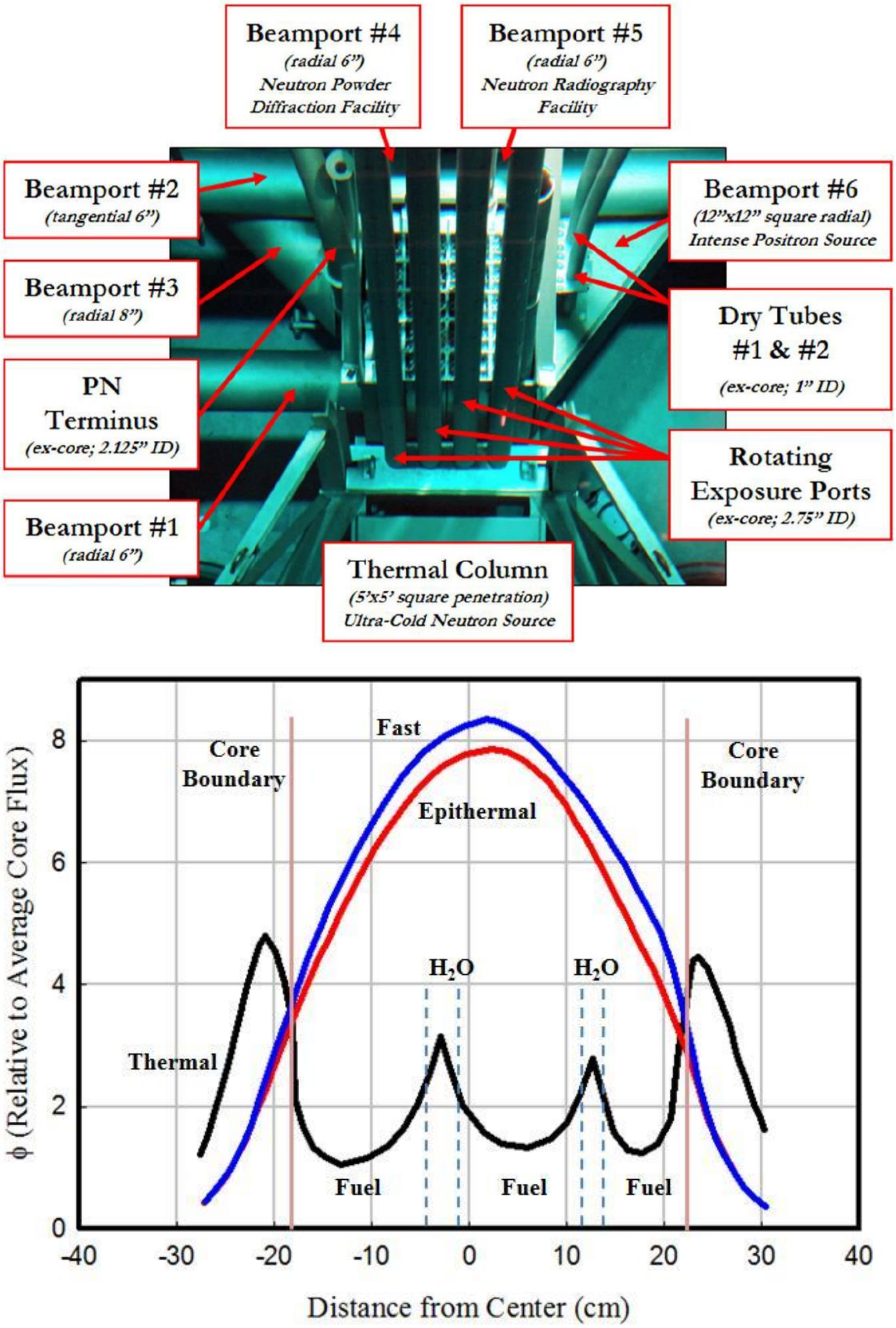

FIG. 2. A picture of the PULSTAR reactor core showing the beam tubes and major irradiation locations (top), and a representation of the neutron flux spatial and energy distribution around the core (bottom).

Figure 3 below shows major beam tube facilities at the PULSTAR. In recent years, these facilities have started to contribute significantly to PULSTAR utilization resulting in a diversified activity portfolio.

FIG. 3. Major PULSTAR facilities including (clockwise) the intense positron beam, the neutron powder diffractometer, the neutron imaging facility, and the ultracold neutron source.

In addition to its irradiation facilities, the PULSTAR reactor pioneered the concept of Internet Reactor Laboratory (IRL) and implemented it at the national and international scales [10]. This concept of experimental reactor physics education is based on providing laboratory modules, such as measurements of the control rod worth levels, observation of approach to the critical state, and quantification of the reactor's feedback behavior, to a remote site through internet based audiovisual and data links. The approach was widely successful and has been adopted by the International Atomic Energy Agency (IAEA) for implementation at various reactors around the world. Recently, the IRL infrastructure at the PULSTAR has been upgraded to support potential course offering in Southeast Asia and Africa. Figure 4 below shows examples of the modern GUIs that are used in current IRL instruction.

3. Strategic Planning, Engagement and Outcomes at the NRP

Guidelines of strategic planning for research reactors are presented in several publications (e.g., see Ref. 11). Therefore, several elements are involved in establishing a strategic plan including a clear definition of the vision and mission of the facility and assessment of all the enabling and hindering factors that affect implementation. However, a key issue that should be recognized is that the strategic plan must be facility dependent and account for local factors to appropriately define and optimize its details. In addition, such plan must be adaptive to adjust to the everchanging environment in which the reactor facility exists.

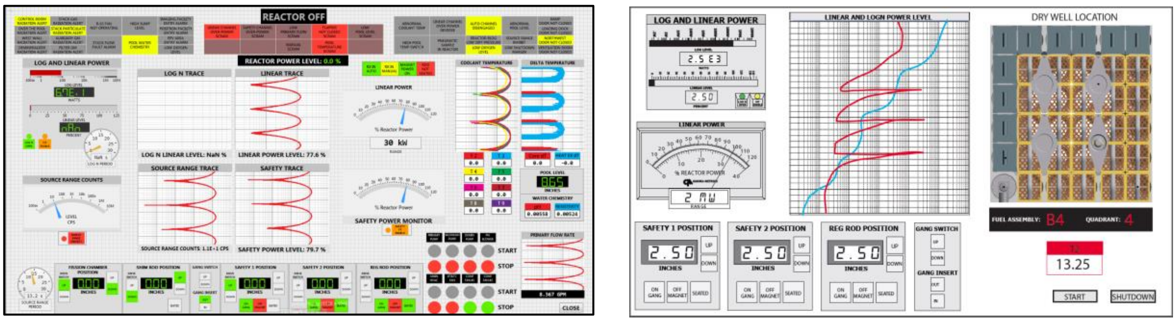

FIG. 4. The IRL's main console GUI (left) and void coefficient measurement GUI (right). GUIs are used by students at the remote site for real-time data acquisition and analysis.

At the NRP, the PULSTAR's strategic approach was established taking into account institutional and national mission objectives. As a university reactor the PULSTAR must meet the NCSU educational, research and outreach objectives. In addition, as a Board of Governor's Center, the NRP (representing the organizational structure within which the PULSTAR is located) must meet institutional viability metrics that are designed to quantify the synergy between the NRP and NCSU missions. Consequently, the following major strategic themes were established

1) Educationally, the NRP would continue to serve its objectives by providing the needed course work to Nuclear Engineering students. However, the impact of the NRP is expanded by pursuing remote and distance education modalities, by offering national and international training and workshop opportunities, and by innovating new classes on the NCSU campus.

2) Initiate multidisciplinary research by establishing facilities and developing techniques that are able to serve a broad base of users. Technically, this aspect capitalized on the characteristics of the PULSTAR to establish unique and state-of-the-art radiation probes of matter.

3) Establish a major infrastructure maintenance and development program. Examples of this program include the effort to upgrade control and monitoring capabilities, reactor power upgrade, and securing future fuel resources. Recently, a new project has been initiated to study physical and cybersecurity aspects of research reactors where the PULSTAR serves as the study's prototype reactor.

4) Establish an NRP outreach program that promotes strategic partnerships to support enhanced utilization of the PULSTAR reactor. Currently, this includes memberships in two important consortia: the US Department of Energy's Nuclear Science User Facilities (NSUF), and the US National Science Foundation's Research Triangle Nanotechnology Network (RTNN).

5) Initiate meaningful and close collaborations with industry. In this case, infrastructure and facilities have been set up to support industrial utilization of the PULSTAR in irradiation testing and nondestructive examination. This approach is highly synergistic with the NCSU approach that promotes intimate localization of industrial and academic collaborators in a unique educational environment.

6) Support PULSTAR development with a knowledgeable human resource capability that is able to sustain infrastructure development and support utilization.

7) Secure the required funding resources for successful implementation of the PULSTAR strategic objectives. A mixed portfolio of funding is needed and is annually generated, which is derived from various governmental and industrial entities.

8) Develop a holistic utilization program that is based on informing a broad spectrum of potential users about available capabilities. Other aspects included in the utilization program are support for the development of instrument dependent user proposals, and a demonstration program that allows potential users to test a specific instrument or capability and understand its benefit for their application.

The above approach was developed and implemented at the NRP over the past 15 years. The outcomes of this approach have been noticeable and affected all the institutional metrics that are reported annually to the university administration. As an educational center, the NRP continued its support of undergraduate education but grew its support of graduate student thesis work to reach nearly 25-30 students annually. For operations and development, the NRP annual expenditures quadrupled. As a research center, the NRP has been and is currently utilized by a multidisciplinary group of researchers from fields such as nuclear engineering, materials science and engineering, chemical engineering, civil engineering, mechanical engineering, physics, and various medical related fields. Furthermore, several non NCSU educational institutions, and industrial and governmental entities are actively utilizing the PULSTAR reactor. Figure 5 below shows the growth of PULSTAR utilization since 2002. On average, the PULSTAR is utilized annually by 25-45 major users with nearly 52% being academic users and 48% otherwise. For the academic users, 40% are from a nuclear engineering background and 60% are from other fields.

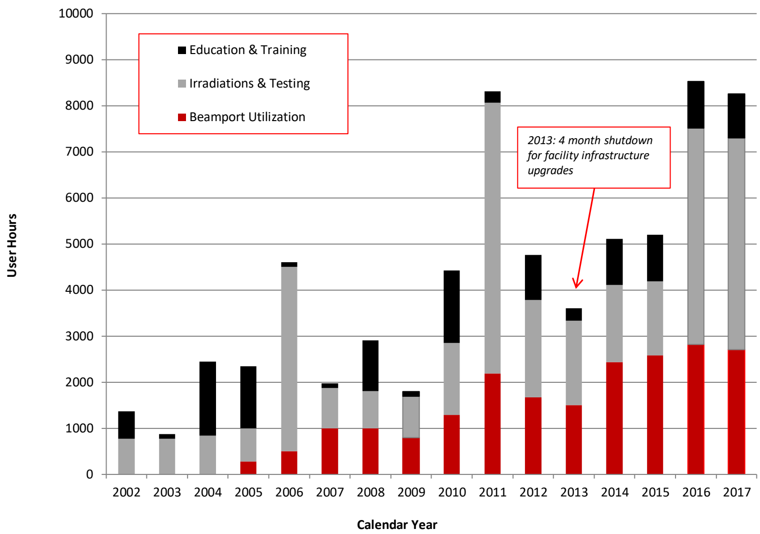

FIG. 5. The growth of the NRP's user hours over the past 15 years. The utilization of beam tube instruments is a new category that emerged over the past 10 years and currently represents 30%-50% of the annual utilization.

Clearly, the above described metrics are correlated. As funding and knowhow resources become available, the development of facilities and capabilities at a given research reactor is promoted. In turn, the developed capabilities attract multidisciplinary users and motivate various applications that enhance scientific and academic production. The final metric, i.e., revenue will naturally follow as one of the indicators of a healthy university research reactor.

4. Conclusions

The evolution and development of the NCSU PULSTAR reactor as a multidisciplinary tool of education and research is discussed. Among academic users of the PULSTAR, 60% originate from non-nuclear engineering fields. The primary conclusion of this experience is the fundamental need to broaden the user base of a research reactor to ensure meeting institutional and national missions. Failure to do so, will result in various degrees of imbalance in meeting typical success metrics, will eventually lead to questioning the viability of the reactor, and may motivate its shutdown.

5. Acknowledgments

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