PULSTAR Reactor Power Upgrade from 1- to 2-MWth

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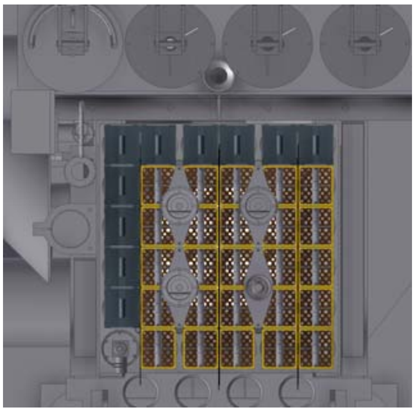
ABSTRACT

An upgrade of the North Carolina State University PULSTAR reactor systems has been completed. The new systems are capable of supporting the increase in the reactor power from 1-MWth to 2-MWth. The PULSTAR is an open pool reactor fueled with uranium dioxide that is enriched to 4% in U-235. Its design characteristics (that include a significant negative power coefficient of reactivity) render it inherently safe during normal operations and under the most sever of potential accidents. The PULSTAR is used in various applications including training and education, radiation testing, neutron activation analysis, and materials nondestructive examination using radiation beams. The completed upgrade included replacement of the primary and secondary cooling systems, a major refurbishment of instrumentation and control systems and installing a new facility-wide radiation monitoring system. In addition, due to increased operational demands, fresh PULSTAR fuel that is enriched to 6% in U-235 will be utilized in the core. The required neutronic and thermal-hydraulic analysis is on-going to support the application to the US Nuclear Regulatory Commission for a license amendment for 2-MW operations. Consequently, it is expected that the introduced system upgrades and core modifications will result in enhancing the core lifetime and in effectively doubling the available radiation (neutron and gamma-ray) flux at the PULSTAR's various in-pool and beam irradiation facilities.

1. Introduction

The history of nuclear research and training reactors at North Carolina State University (NCSU) was initiated in 1949 and culminated in 1953 with the operation of the first nuclear reactor on a university campus in the world. That reactor, known as the Raleigh Research Reactor I (RRR I), operated at a power of 10-kW and had a homogenous core that was fueled by a mixture of uranyl sulphate. It was issued the R-1 license by the US Atomic Energy Commission. Due to operational difficulties the reactor was shut down in 1955. Following the R-1 reactor, two more reactors were operated and shutdown on the campus of NCSU. Finally, in 1968 the construction of the fourth reactor, i.e., the PULSTAR was initiated. In 1972, the PULSTAR achieved its first criticality at a power of 1-MWth. Since then and to date, the PULSTAR reactor continues its operation in support of the mission of NCSU in education, scientific discovery, and community service and outreach [1].

The PULSTAR represents an open pool and light water moderated and cooled reactor that is fueled with uranium dioxide (UO_2) enriched to 4% in U-235. The fuel is configured into assemblies that contain 25 fuel pins each and are arranged in a square 5×5 array. The fuel pins are clad with Zircaloy 2 cladding. The core contains 25 assemblies that are arranged in a 5×5 square array. In addition, four Ag-In-Cd control rod blades are utilized in the core. Figure 1 shows a schematic of the PULSTAR core and a cutaway of a typical fuel assembly. To enhance the core's neutron economy and to extend its lifetime, beryllium reflectors are used on two sides of the core. For utilization purposes, vertical irradiation access tubes are placed at the core periphery and are routinely used in materials testing experiments. In addition, the PULSTAR is equipped with a pneumatic system that can place samples in close proximity to the core to perform neutron activation analysis irradiations. Furthermore, the core is surrounded by 5 beam tubes and has a sixth through beam tube. These beam tubes have been the subject of much development in the past few years resulting in the installation of an advanced neutron imaging facility, a neutron powder diffraction system, an intense positron beam, and an ultracold neutron source. These facilities have resulted in establishing the PULSTAR as a center for fundamental and applied research in neutron physics and the characterization of nanomaterials. Figure 2 shows a layout of the PULSTAR bay floor and its various beam tube facilities [2-5].



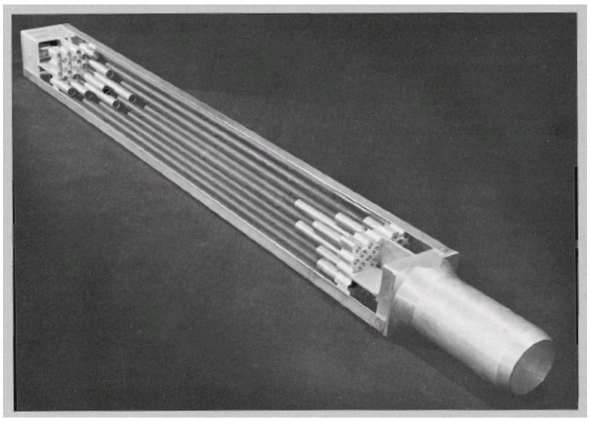


Fig 1. A top view of the current PULSTAR core (left) and a cutaway of a typical fuel assembly (right).

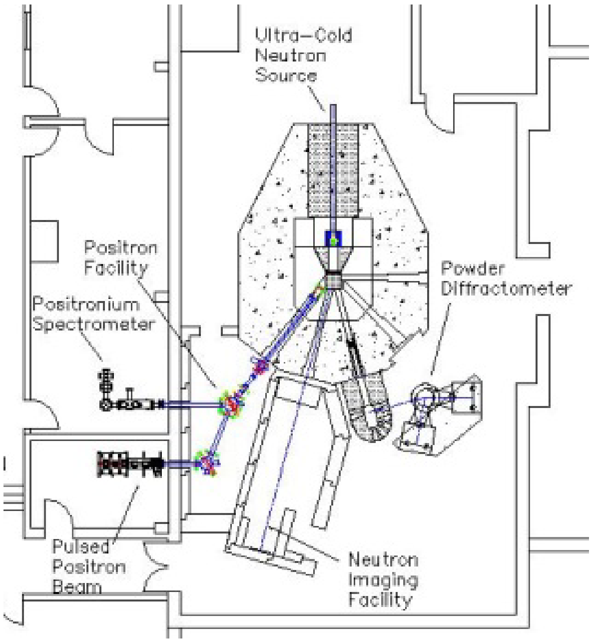


Fig 2. A schematic of the PULSTAR bay floor showing various beam tube facilities.

Finally, it should be noted that due to the use of UO_2 fuel and its low enrichment, the PULSATR reactor is characterized with a negative reactivity feedback behavior, as quantified by its power coefficient of reactivity (PCR), that reaches -330 pcm/MW. This is considered relatively large especially when compared to other common research reactor designs, e.g., MTR reactors, which typically have a PCR that is lower by an order of magnitude or more. Furthermore, the design of the PULSTAR reactor core represents a highly under moderated system that results in the thermal neutron flux reaching its peak at the periphery of the core and at the entrance of the beam tubes. This results in preferential leaking of thermal neutrons into the beam tubes and in turn enhanced fluxes at the sample positions for the various facilities that are shown in Fig. 2.

2. PULSTAR Systems Upgrade

The upgrade of the PULSATR systems was executed to allow increasing its power form 1- to 2-MWth. This increase in power would directly support its educational and research activities. Fundamentally, the PULSTAR represents an intense radiation (neutron, gamma-ray and positron) source. Consequently, doubling its power is expected to result in effectively doubling the available radiation fluxes that are useable in the applications described above. In addition, as a part of the upgrade process, plans are currently underway to allow the refueling of the PULSTAR core with fresh UO_2 fuel assemblies that have identical configuration to the current assemblies (see Fig. 1) but are enriched to 6% in U-235.

In terms of hardware, the upgrade involved a complete refurbishment of the primary and secondary cooling systems for the PULSTAR reactor (Fig. 3). This process (and the commissioning of the new systems) was executed during a 4-month shutdown period. In this case, the starting point for the new system design was the preservation of all safety and operational margins that characterized the old system and that comprised its licensing basis as set in the PULSTAR's Safety Analysis Report and its Technical Specifications [6]. Consequently, new primary and secondary pumps (controlled by variable frequency drives), nitrogen (N-16) delay tanks, a plate-type heat exchanger, and the supporting valves and coolant flow pipes that are capable of supporting flow rates up to 1000 gallons per minute (vs. the original 500 gallons per minute) were installed. In addition, the original cooling tower was maintained but refurbished to support the increase in power and also equipped with variable speed fan capability and instrumentation, which allows automatic regulation of the fan speed to permit holding the coolant pool inlet temperature at a given set point. This capability allows operating the reactor at its maximum power even on days when the ambient temperature and humidity may approach or reach abnormal highs, which sometimes was not possible under the old system's configuration. The upgrade also included the installation of a secondary system coolant filtration unit, which is expected to reduce the long term maintenance needs and costs.

Upon completion of the systems upgrade process, the commissioning activities for the new system were initiated to perform coolant filling and leak testing, instrument calibrations to support flow and temperature measurements, pump testing and measurement of flow curves, and testing of coolant filtration units. The return of the PULSTAR reactor to operations at the licensed power of 1-MWth was gradually performed by operating at 50%, 90%, 95% and 100% power over a 3-week period. Finally, it should be noted that the installation and commissioning of the new PULSTAR reactor systems was performed following US NRC regulations as prescribed in 10 CFR 50.59 and after approval of the NCSU campus reactor and radiation safety committees [7].

To support the licensing requirements of the PULSTAR reactor power upgrade, neutronic and thermal-hydraulic analyses of the reactor core and systems have been initiated. The neutronic analysis is performed using the MCNPX code package and is utilized to predict the PULSTAR performance capabilities in a mixed enrichment (4% and 6%) configuration [8]. This includes estimating parameters such as the core's excess reactivity, shutdown margin, reactivity coefficients, and kinetic parameters such as the effective delayed neutron fraction and the prompt neutron lifetime. In addition, the core power distributions are calculated and provided for utilization in the thermal-hydraulic analysis to support predictions of safety performance under steady state and transient operational scenarios. Figure 4 shows a layout of the MCNPX model for the PULSTAR core. The validity of the MCNPX model is investigated using PULSTAR data that was measured since the start of its operation in 1972 and to the present day. The measurements include core depletion data, control rod worth information, and power distributions. To date, reasonable agreement has been found between model calculations and the historical data (e.g., see Fig. 4). Currently, the thermal-hydraulic analysis is underway and is utilizing the RELAP5-3D code package [9]. Nonetheless, due to the core power and flow characteristics, it is anticipated that the conservative PULSTAR safety margins, which were predicted during steady state operations and for the potential transient scenarios at 1-MWth, will persist as the power is raised to 2-MWth.

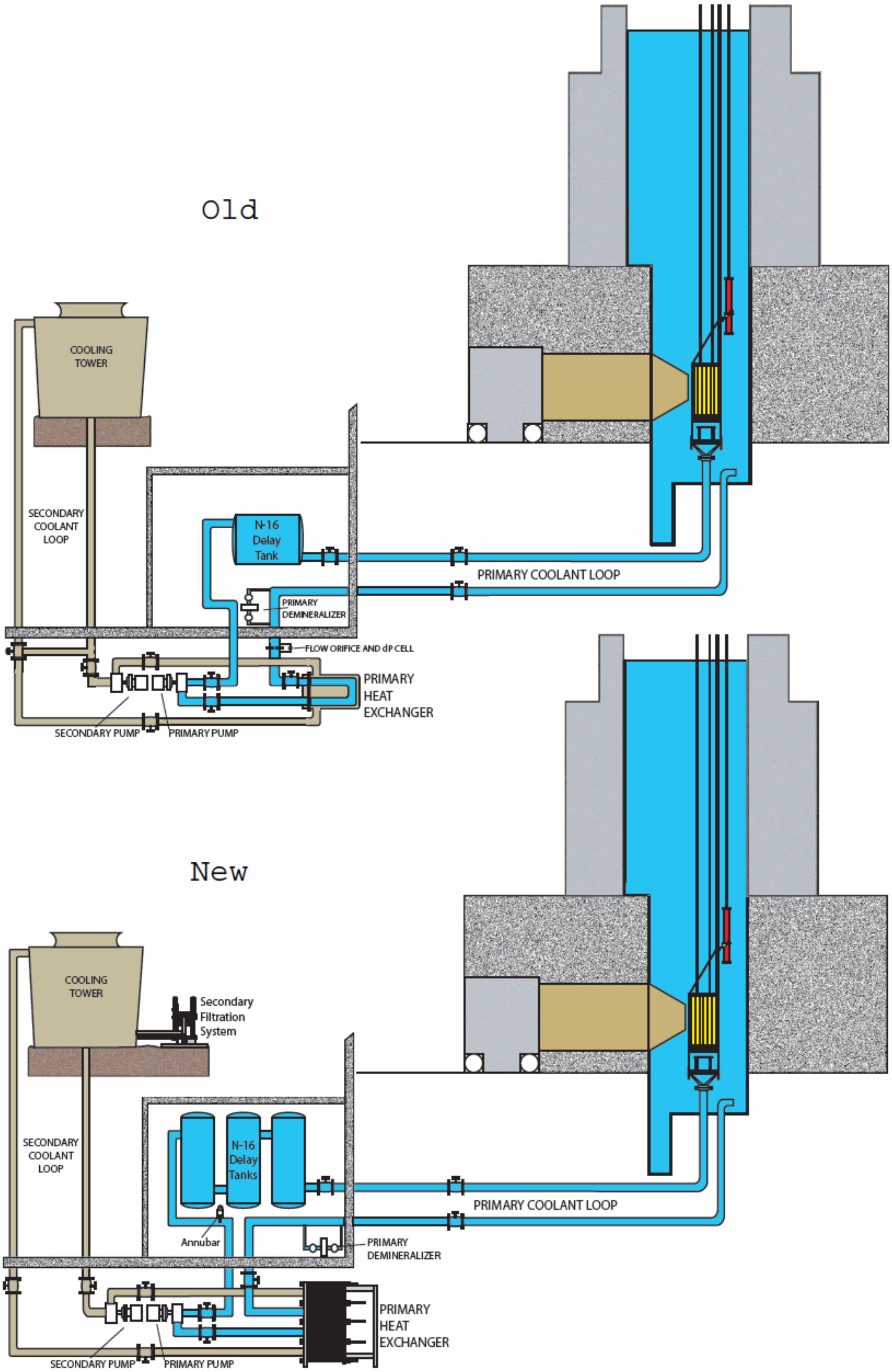


Fig 3. A schematic of the PULSTAR reactor upgrade of the primary and secondary systems.

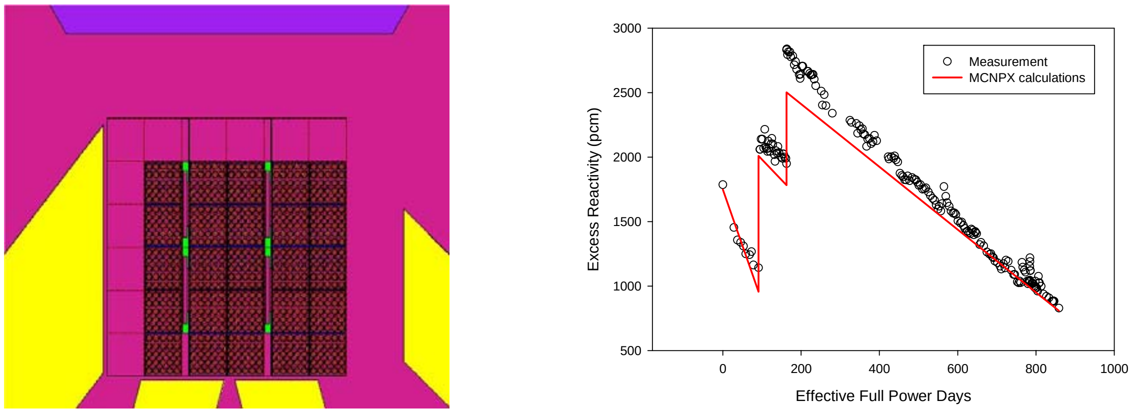


Fig 4. The PULSTAR reactor MCNPX core model (left) and the measured vs. predicted core depletion for the period of 1972-1999 (right).

3. Conclusions

An upgrade of the NCSU PULSTAR reactor primary and secondary cooling systems has been completed. Operation of the reactor at its currently licensed power of 1-MWth has been resumed. The new systems are capable of supporting operation up to a maximum power of 2-MWth. Analysis to obtain the license for operation at 2-MWth is expected to be completed in the near future.

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