Multidisciplinary Engagement at Research Reactors: The NCSU PULSTAR

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What is a Research Reactor?

- A Research reactor is a source of radiation

  - It primarily produces neutrons and gamma-rays
    - Using this primary radiation, secondary radiation can also be produced

  - The produced radiation can be used for performing studies either in the core of the reactor or can be guided to be used in ex-core experiments

- While the reactor does not usually produce electricity, it can be used to understand the fundamental concepts that are relevant to the safe operation and control of electricity producing reactors
Mission

- **Education / Training**
  - Provide a hands-on understanding of the physics and operations of nuclear reactors to the next generation of nuclear engineers
  - Serve as a multi-disciplinary education center in the area of radiation physics applications
  - Provide training in support of nuclear power development

- **Scientific applications and research**
  - Develop state-of-the-art facilities for understanding and applying the principles of radiation interaction with matter
    - Includes in-pool and ex-pool studies

- **Outreach, extension and service**
  - Support the national infrastructure through the use of nuclear methods in various aspects including medical and industrial
University Research Reactors

1. Idaho State University
2. Kansas State University
3. Massachusetts Institute of Technology
4. Missouri University of Science & Technology
5. North Carolina State University
6. Oregon State University
7. Pennsylvania State University
8. Purdue University
9. Reed College
10. Rensselaer Polytechnic Institute
11. Rhode Island Nuclear Science Center
12. Texas A&M University
13. The Ohio State University
14. University of California, Davis
15. University of California, Irvine
16. University of Florida
17. University of Maryland, College Park
18. University of Massachusetts, Lowell
19. University of Missouri, Columbia
20. University of New Mexico
21. University of Texas at Austin
22. University of Utah
23. University of Wisconsin, Madison
24. Washington State University
Nuclear Reactor Program
Board of Governors Center

- The first open access nuclear reactor in the world (envisioned 1949, operated 1953) was the R-1 reactor at NC State University

PULSTAR Reactor
1972
1-MW
PULSTAR Reactor

- 1-MW power
  - Upgrade to 2-MW
- Open pool/tank
- Light water moderated and cooled

Critical 1972
PULSTAR Reactor

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- 5 x 5 array of fuel assemblies
- 5 x 5 array of pins

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- 5 x 5 array of fuel assemblies
- 5 x 5 array of pins
- Sintered UO₂ pellets
- 4% and 6% enriched

Critical 1972
PULSTAR Characteristics

- **Design**
  - Heavy loading of U-235 -- 12.5 kg
  - Low number of H to U-235 atoms
  - High ratio of fast to thermal flux in the core
  - High fast-neutron leakage
  - High sensitivity to reflector material
  - Long core lifetime
Irradiation Locations

- **Beamport #4** (radial 6"")
  - Neutron Powder Diffraction Facility
- **Beamport #5** (radial 6"")
  - Neutron Radiography Facility
- **Beamport #2** (tangential 6"")
- **Beamport #3** (radial 8"")
- **PN Terminus** (ex-core; 2.125" ID)
- **Beamport #1** (radial 6"")
- **Beamport #6** (12"x12" square radial)
  - Intense Positron Source
- **Dry Tubes #1 & #2** (ex-core; 1" ID)
- **Rotating Exposure Ports** (ex-core; 2.75" ID)
- **Thermal Column**
  - (5'x5' square penetration)
  - Ultra-Cold Neutron Source
Development Strategy
LICENSE AMENDMENT
FOR THE USE OF 6% ENRICHED FUEL

Nuclear Reactor Program
NORTH CAROLINA STATE UNIVERSITY
RALEIGH, NORTH CAROLINA 27695

LICENSE NO. R-120
DOCKET NO. 50-297
March 12, 2015

PULSTAR REACTOR
UPDATED
SAFETY ANALYSIS REPORT

NORTH CAROLINA STATE UNIVERSITY
RALEIGH, NORTH CAROLINA 27695

LICENSE NO. R-120
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29-MARCH-2017
Development Strategy

- **Capabilities**
  - Enhance neutron flux at all irradiation locations

- **Longevity**
  - Ensure long term operation of reactor

- **Institutional mission**
  - Multidisciplinary facility
    - Instrument the reactor for a wide user base
Major Capabilities

- Neutron powder diffractometer
- Neutron imaging
- Intense positron beam
- Ultracold neutron source (under testing)
- Fission gas release loop (design & construction)
- Neutron activation analysis
- In-pool irradiation testing facilities

PULSTAR reactor bay
Intense Positron Beam Facility
Bulk Positron System

- Two Hamamatsu H3378-50 PMTs
- LeCroy 760Zi-A digital oscilloscope to digitize the raw PMT pulses and acquire PALS spectrum
- Time resolution ~200 ps
- Analog system operating in parallel, and is used for high count rate and calibration
- HPGe detector for DBS
- Linkam pressure chamber with temperature control from 77K to 673K
Thermal Neutron Imaging

Beam Indicator
Light

Dose Monitors

Tomography controller equipment

Beam Shutter

Camera box

Scintillator

Entrance Door

CCTV

Beam Control Computer

CCD Camera and Tomography Controller LabView Interface

Camera Status

Camera ON

CCT Temperature

CCD Temperature

Set Temperature (Default: 78 degree Centigrade)

Set exposure time [sec] (seconds)

Start Acquisition

Shut Down Camera

Heavy Concrete Shielding

CCD Camera and Tomography Controller Equipment
PULSTAR Powder Diffractometer

- Beam Tube 4 – two 3” sapphire fast neutron filters.
- Si bent perfect crystal focusing monochromator – 1.479 Å beam at sample position.
- Large area position sensitive neutron detector array 15” by 24” spanning 20° for high resolution.
- Detector rotates on air pad supports.
FGR Measurement Facility

- Supporting structure and water, gas, electric lines
- Biological shield
- Service ports and pumping chamber
- Long throw manipulator
  For linear beam head motion
- Heat exchanger
- Heat insulation
- Thermal Block
- Sample Holder
- Water cooled chamber

Furnace Beam Head
Utilization

- Metals and semiconductors (defects, fatigue)
- Nuclear materials (radiation damage characterization)
  - Graphite and SiC
- Nuclear fuel (microstructure and performance)
- Polymers morphology
  - Free volume, glass transition, thin films
  - Nanocomposite, immobilized layer
  - Diffusion barriers, capping layers, pore sealing
  - Membranes for gas/liquid filtration
- Nanoporous low-$k$ dielectrics
- High surface area materials (energy storage, gas filtration)
- Construction and shielding materials
  - Imaging
- Instrument and component performance testing
  - In situ monitoring
- Elemental analysis
Nuclear Energy Related Research

- **Advanced Nuclear Reactors**
  - Irradiation and characterization of materials
  - Methods and measurements of fundamental data (cross sections) for neutron thermalization.
    - Applies to advanced reactors (e.g., High Temperature Reactors and Salt Moderated/Cooled Reactors)

- **Nuclear Fuel Characterization and Assay**
  - Fuel testing loop for investigating fission gas release
  - Fuel burnup and enrichment assay
  - Digital radiation measurement instrumentation for high intensity conditions

- **Security of Research Reactors**
  - Cybersecurity integration in research reactors
The Internet-based remote learning tool is being used to train nuclear engineering students.

By Dick Kovan

The International Atomic Energy Agency established its Internet Reactor Laboratory (IRL) program as one solution for a country that has a research reactor to provide practical reactor operating experience to nuclear engineering students, usually—but not always—in IAEA member states that do not have a research reactor.

The IRL concept was originally developed by a U.S. Department of Energy–funded research reactor consortium in which North Carolina State University (NCSU) successfully demonstrated that an Internet computer link could deliver practical experiments from its PULSTAR reactor to students at other universities in the United States. The next step—to develop the concept internationally—grew from an existing relationship between NCSU and the Jordan University of Science and Technology (JUST), which had set up the country’s first nuclear engineering program in 2007 to supply Jordan’s nuclear energy program with fully qualified nuclear engineers. The IRL project was inaugurated at JUST’s Department of Nuclear Engineering in November 2010.

Complement Vietnamese university nuclear curriculum programs with the Department of Energy supported remote reactor training from North Carolina State University.
Partnerships

- National and International partnerships
  - Partner in the DOE/INL NSUF
    - Experiments conducted at PULSTAR
  - Partner with DOE and DOS to develop international educational programs
    - New international internet reactor lab offering
  - Partner in NSF’s RTNN (Research Triangle Nanotechnology Network)
  - Lead of OECD/NEA WPEC SG42 TSL data group
  - Collaborate with IAEA in various activities

All the above resulted in increasing utilization
Utilization Metrics

- UNC system “Board of Governors Center”
  - Instrumented to be multidisciplinary

- Annually 5000 – 10000 user hours
  - 40% external to UNC system

- Academic users 52%
  - 40% nuclear engineering

- Non academic users 48%

Utilization Metrics Graph:

- Education & Training
- Irradiations & Testing
- Beamport Utilization

2013: 4 month shutdown for facility infrastructure upgrades
The Nuclear Reactor Program (NRP) at NCSU is a multidisciplinary UNC system center that is dedicated to serving the educational and research needs of internal and external users. Full support of users including work with irradiated materials.

The PULSTAR reactor can provide state-of-the-art irradiation and materials examination services. The available facilities are complementary of national facilities. Capabilities can be offered on-site and monitored remotely (e.g., using the internet).

Partnership and collaboration (national and international) are key in NRP development and utilization strategy.