Multidisciplinary Engagement at Research Reactors: The NCSU PULSTAR

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18th IGORR Conference and IAEA Workshop
December 3 – 7, 2017 • Sydney, Australia

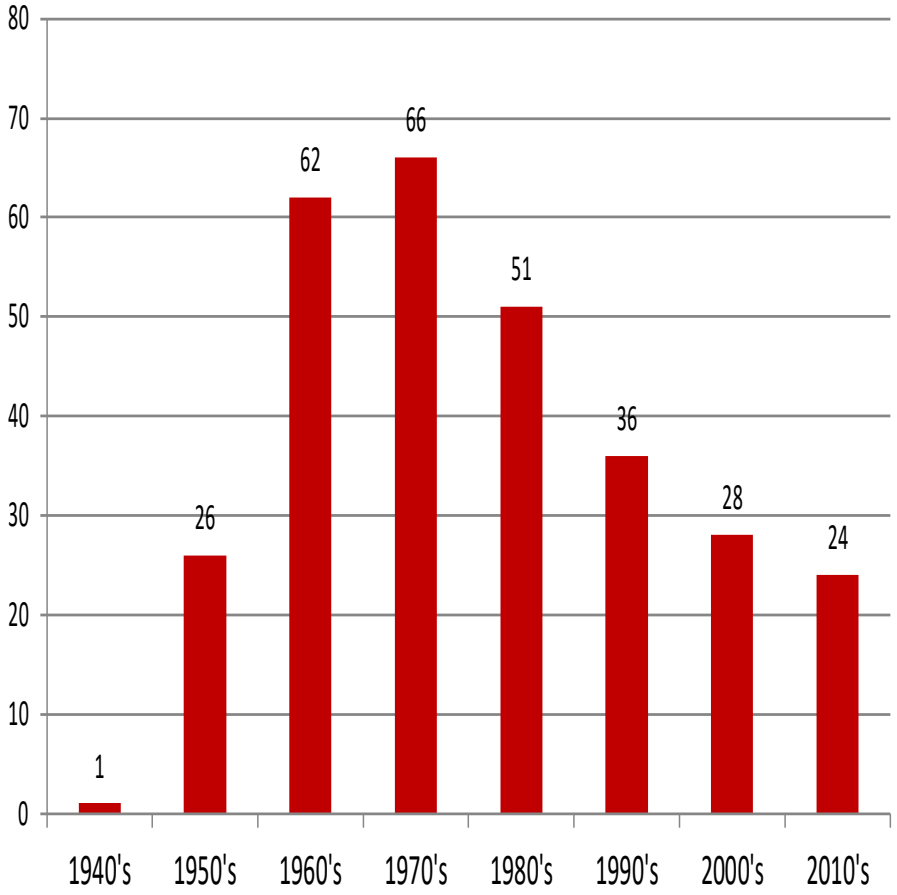
What is a Research Reactor?

- 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

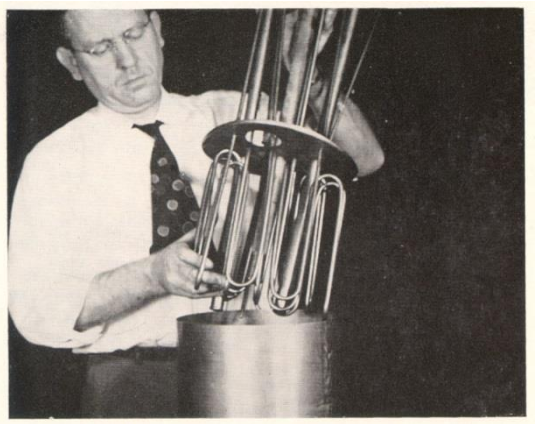


1	Idaho State University	13	The Ohio State University
2	Kansas State University	14	University of California, Davis
3	Massachusetts Institute of Technology	15	University of California, Irvine
4	Missouri University of Science & Technology	16	University of Florida
5	North Carolina State University	17	University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

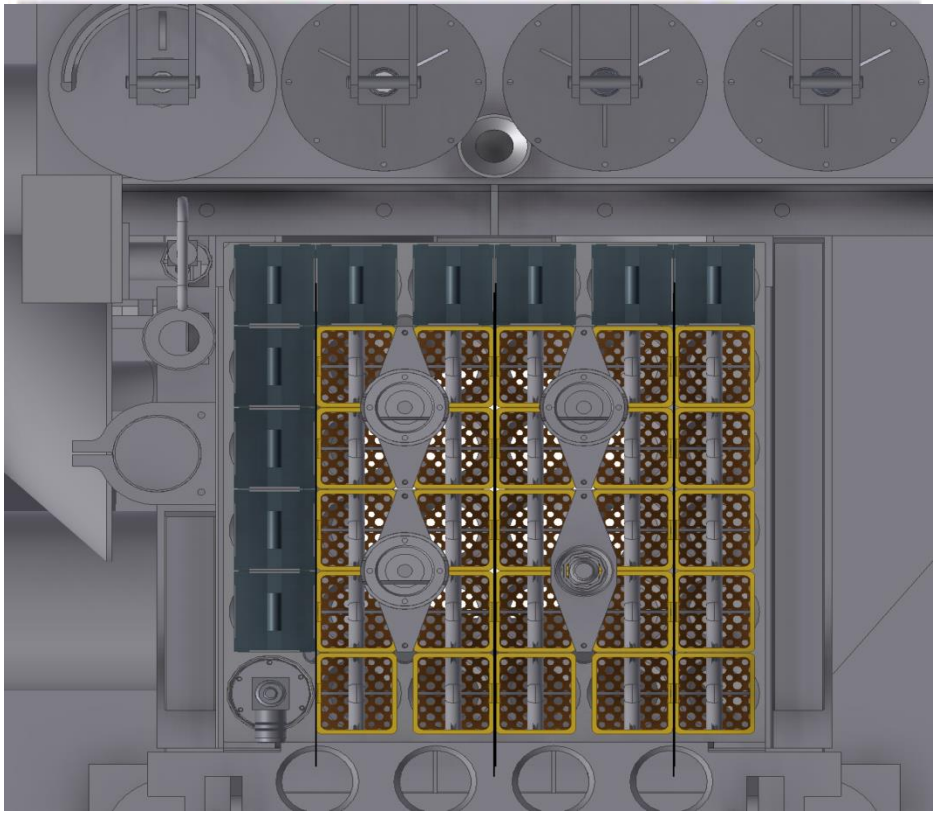
PULSTAR Reactor

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

Critical 1972

PULSTAR Reactor

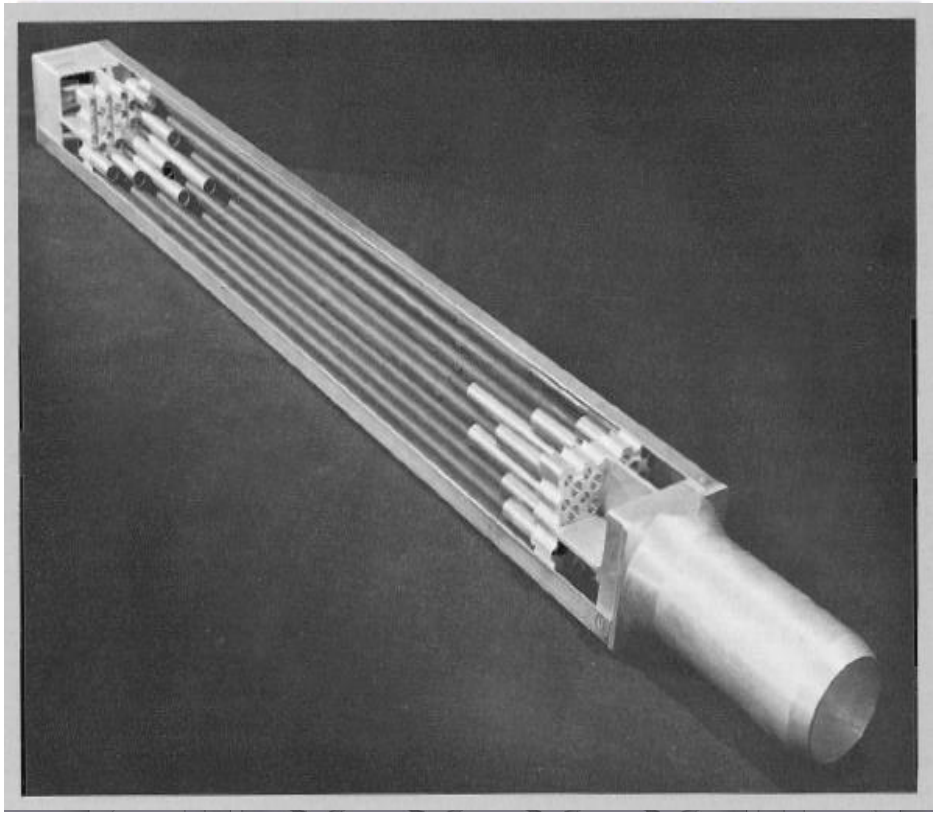
- 1-MW power
  - Upgrade to 2-MW
- Open pool/tank
- Light water moderated and cooled
- 5 x 5 array of fuel assemblies
- 5 x 5 array of pins



Critical 1972

PULSTAR Reactor

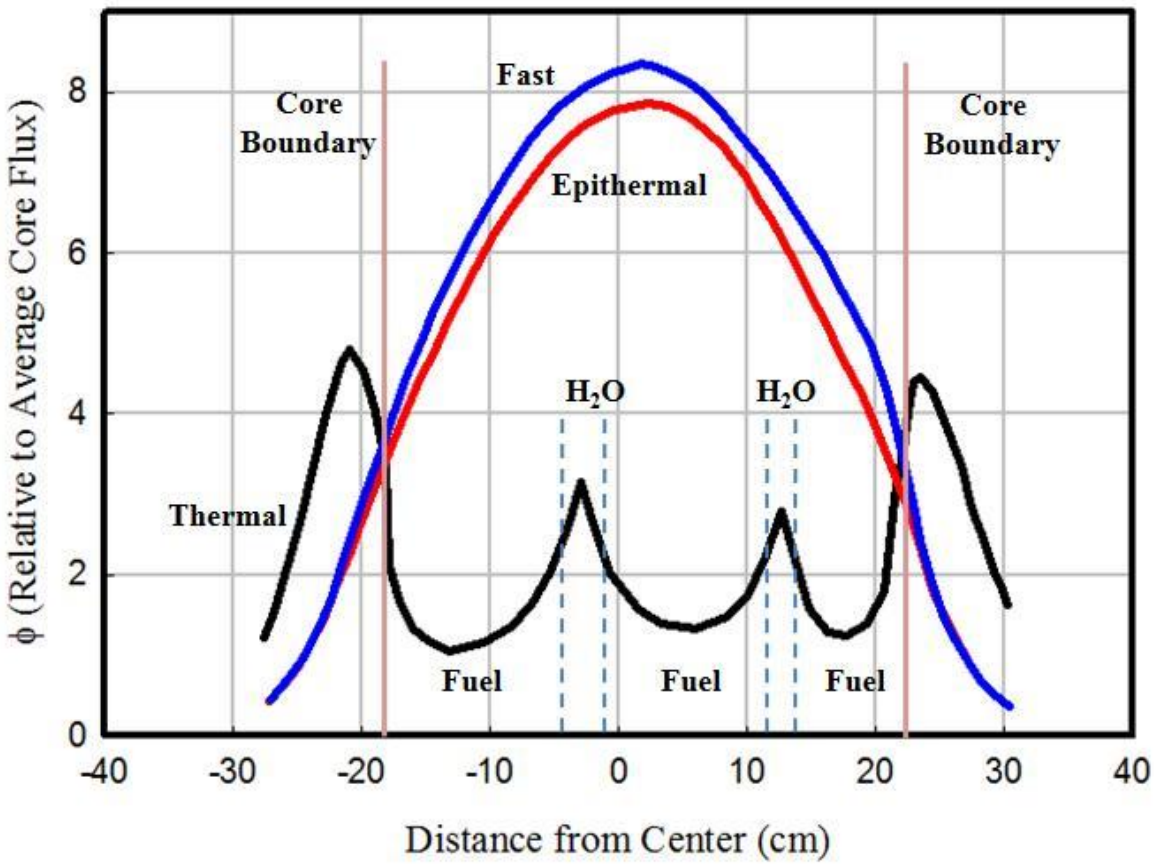
- 1-MW power
  - Upgrade to 2-MW
- Open pool/tank
- Light water moderated and cooled
- 5 x 5 array of fuel assemblies
- 5 x 5 array of pins
- Sintered UO_2 pellets
- 4% and 6% enriched



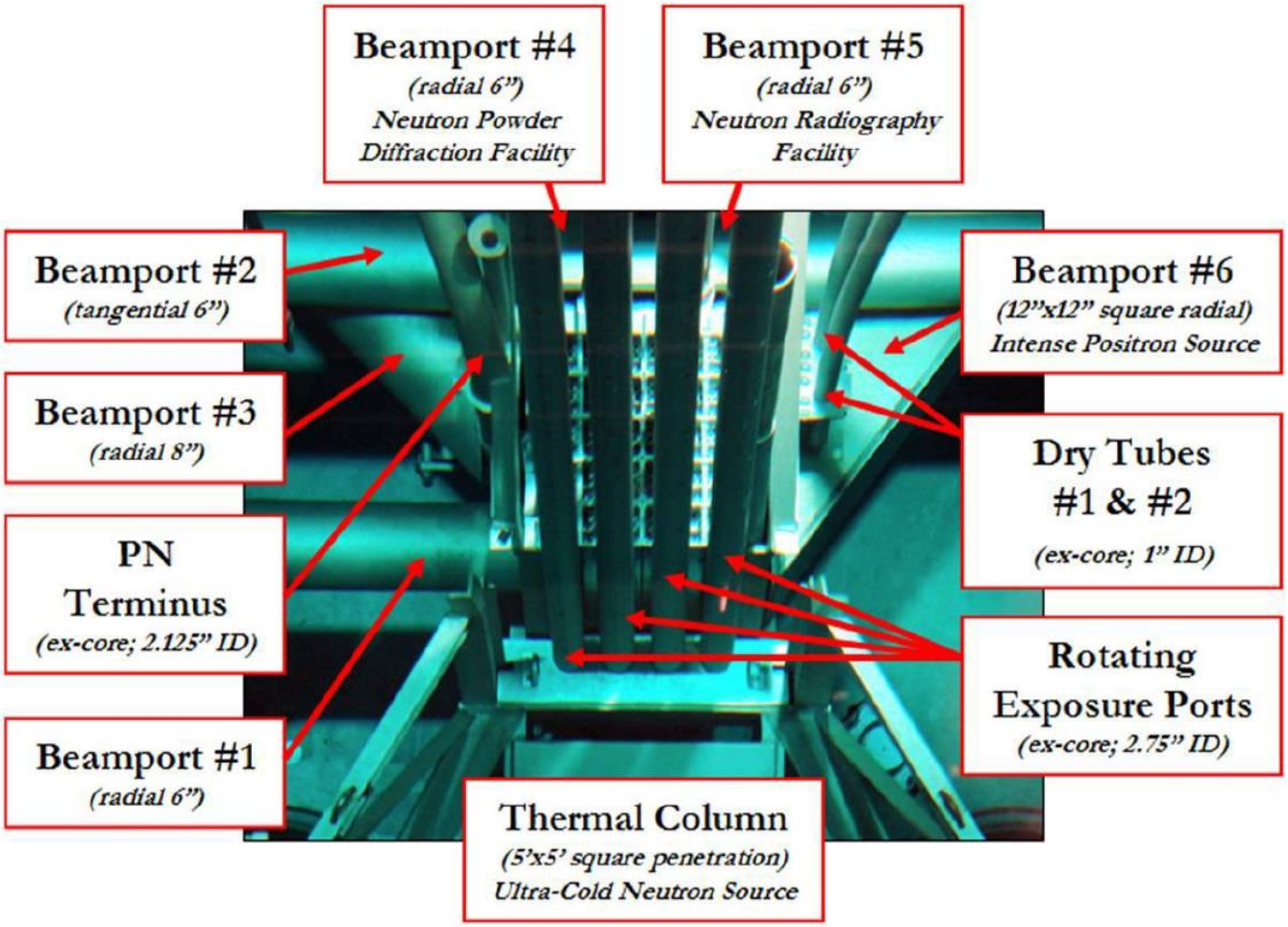
Critical 1972

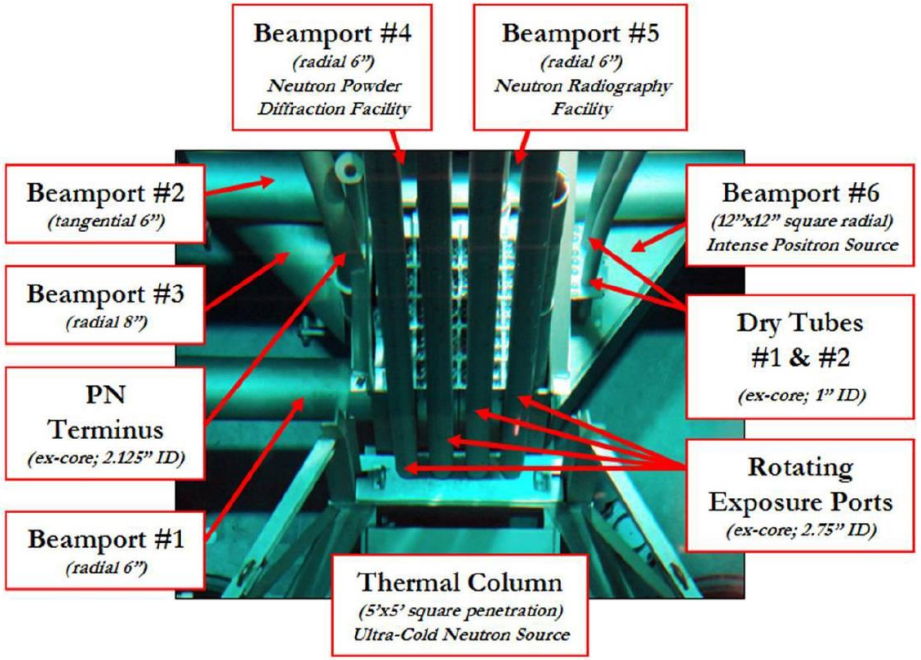
PULSTAR Characteristics

- 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





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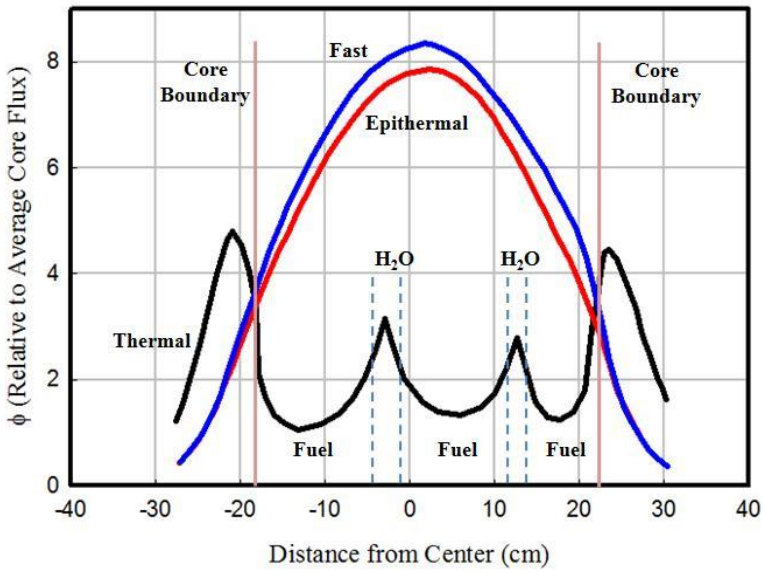

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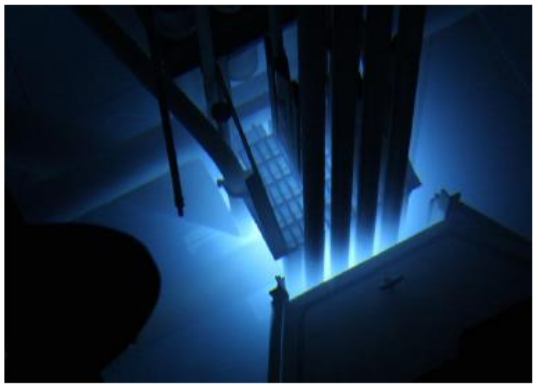
Development Strategy

NC STATE UNIVERSITY

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

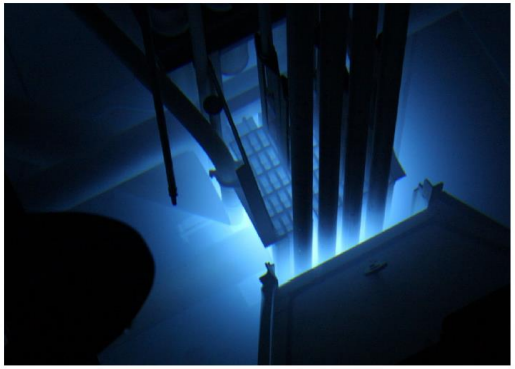
NC STATE UNIVERSITY

PULSTAR REACTOR

UPDATED

SAFETY ANALYSIS REPORT

NORTH CAROLINA STATE UNIVERSITY
RALEIGH, NORTH CAROLINA 27695



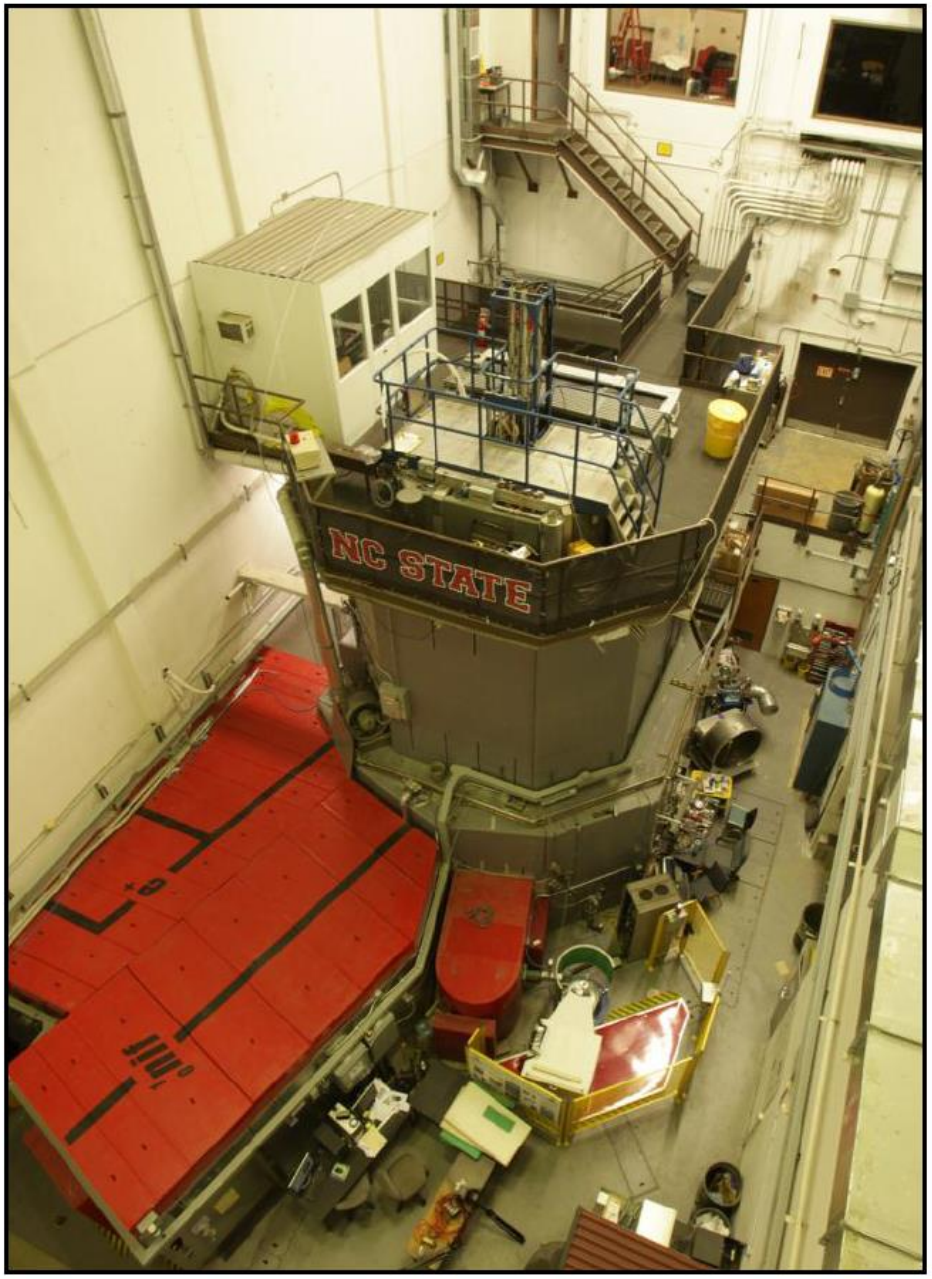
LICENSE NO. R-120
DOCKET NO. 50-297
29-MARCH-2017

Development Strategy

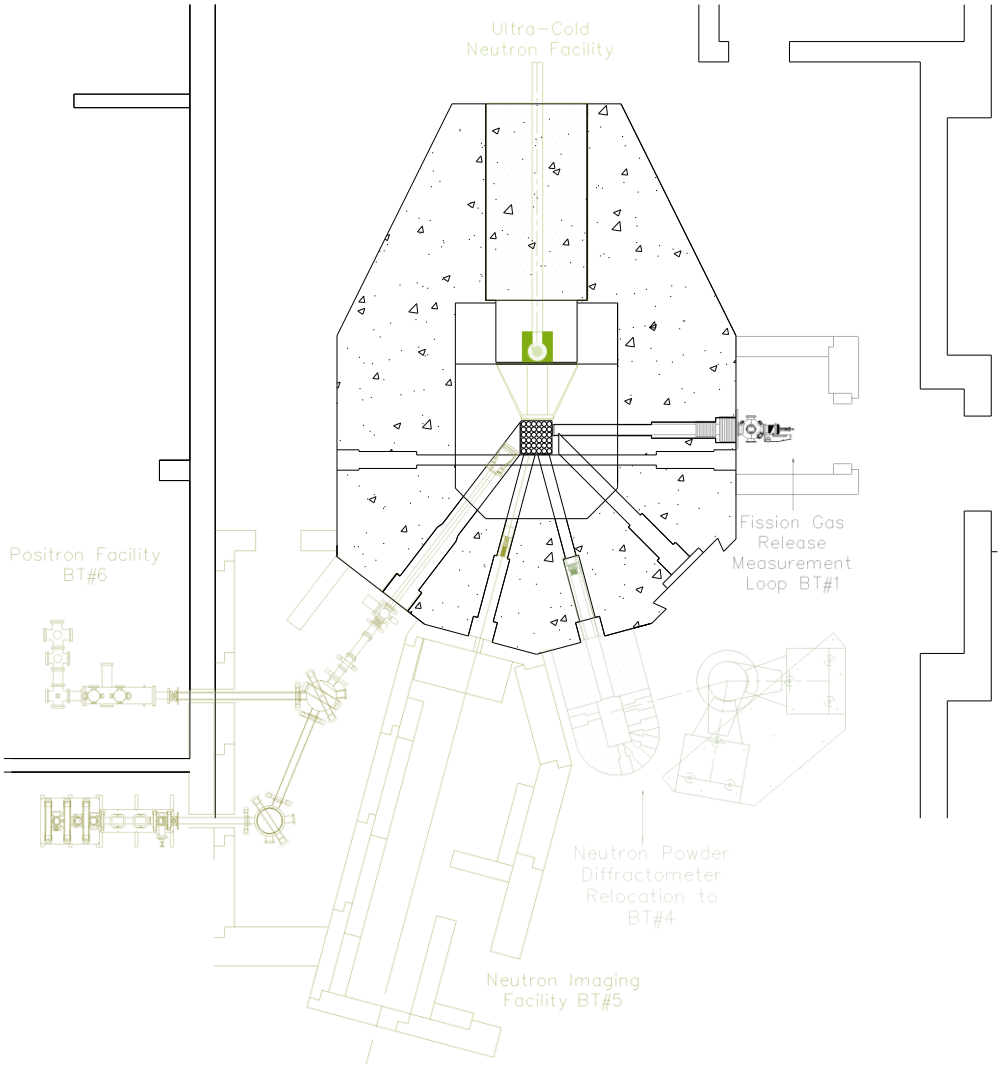
- **Capabilities**
  - Enhance neutron flux at all irradiation locations
- **Longevity**
  - Ensure long term operation of reactor
- **Institutional mission**
  - **Multidisciplinary facility**
    - Instrument the reactor for a wide user base

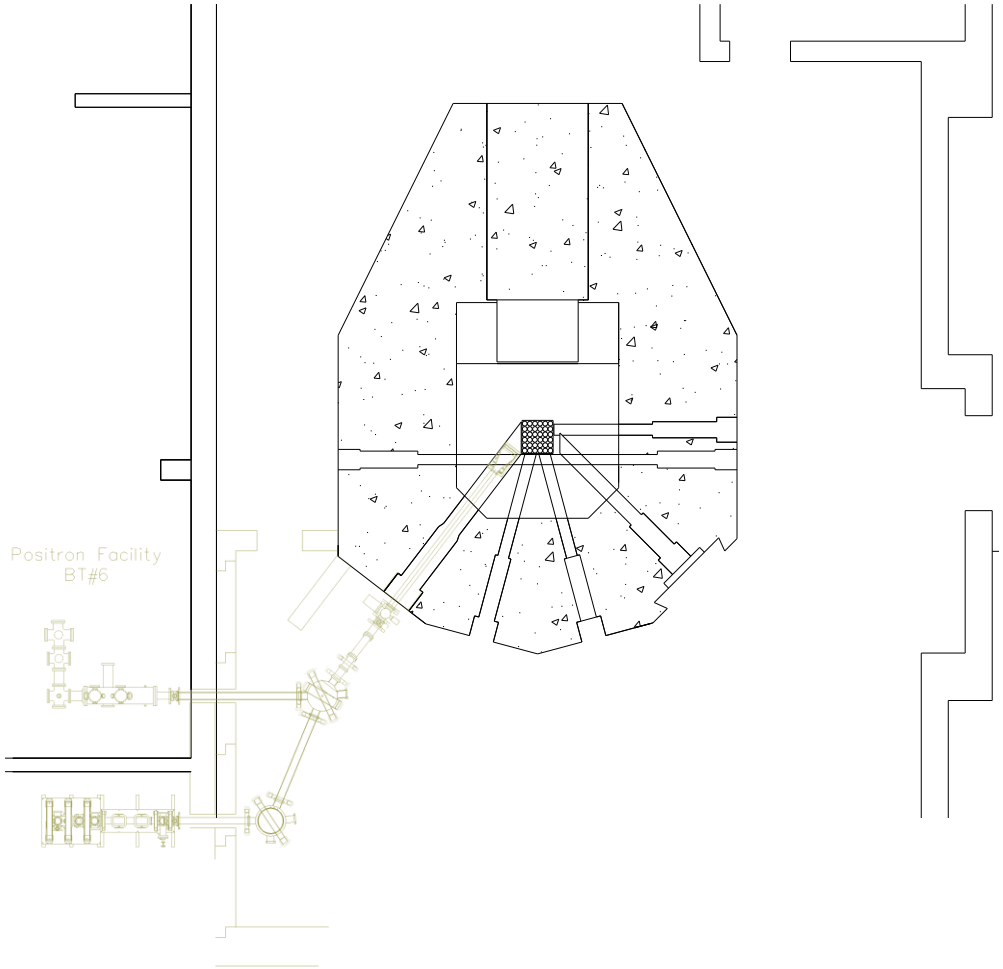
Major Capabilities

- 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

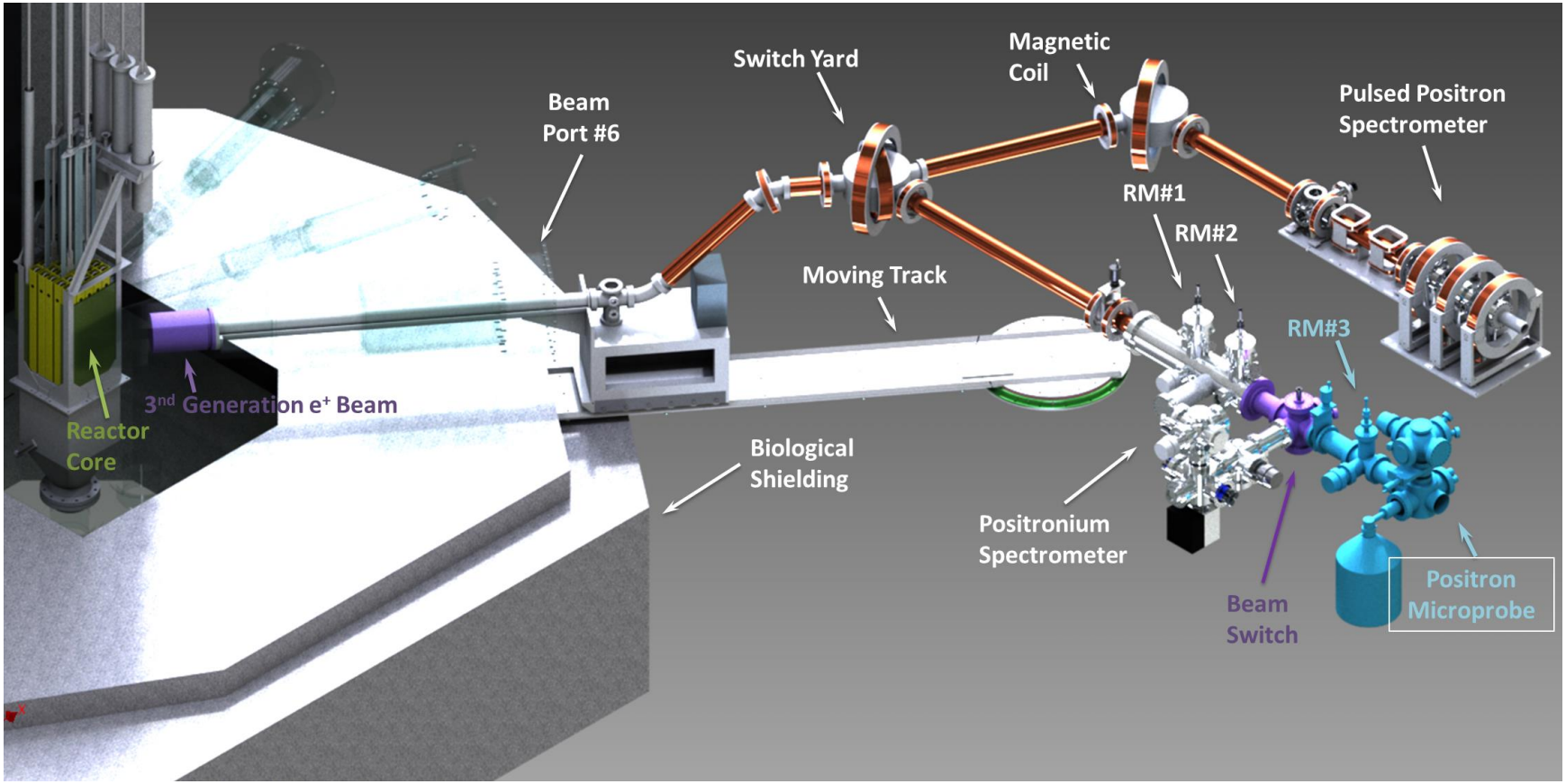


PULSTAR reactor bay

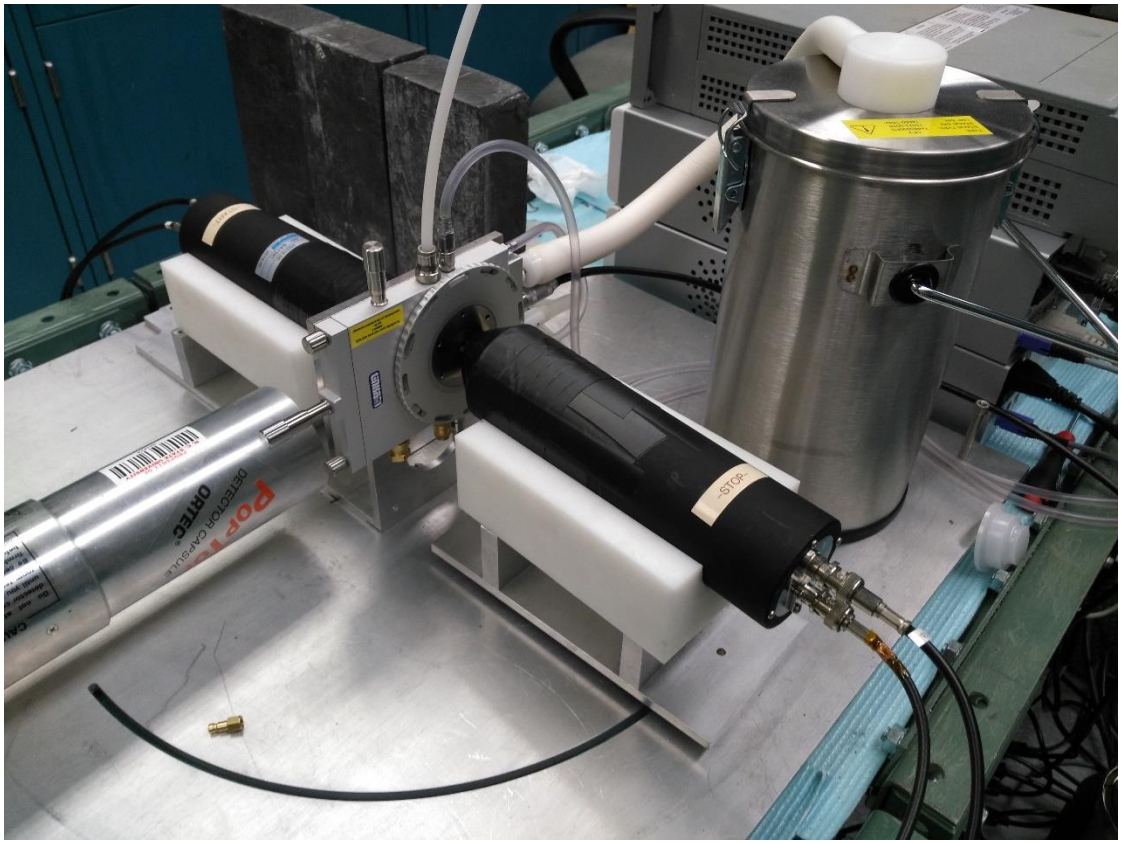

Ultra-Cold
Neutron Facility
Positron Facility
BT#6
Fission Gas
Release
Measurement
Loop BT#1
Neutron Powder
Diffractometer
Relocation to
BT#4
Neutron Imaging
Facility BT#5


Positron Facility
BT#6

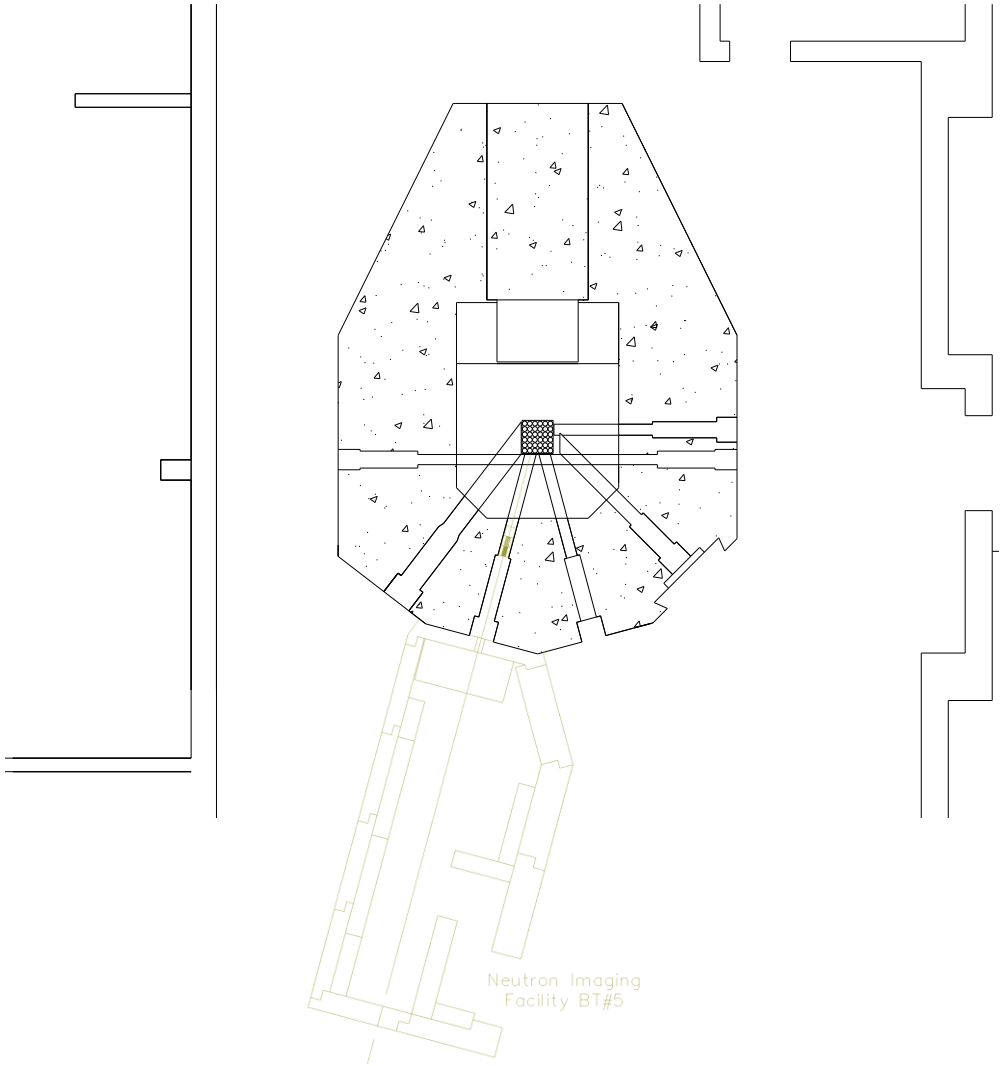
Intense Positron Beam Facility



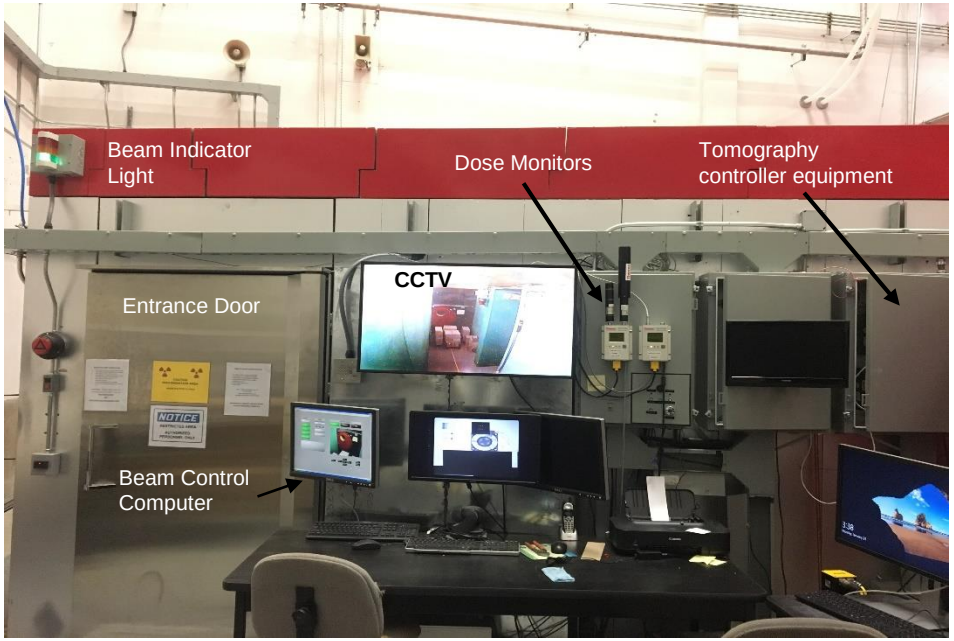
Bulk Positron System

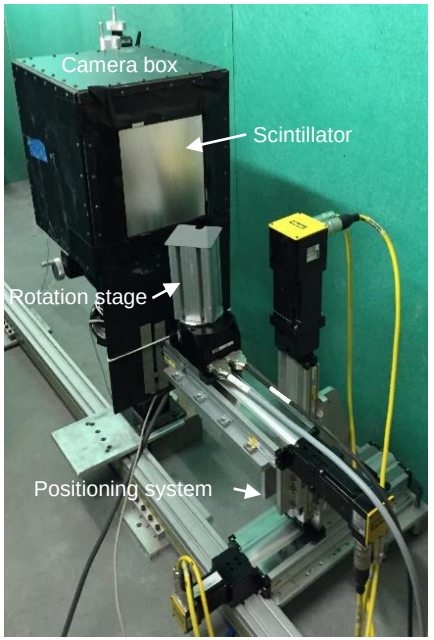


- Two Hamamatsu H3378-50 PMTs
- LeCroy 760Zi-A digital oscilloscope to digitize the raw PMT pulses and acquire PALS spectrum
- Time resolution ~200 ps
- Analog system operating in parallel, and is used for high count rate and calibration
- HPGe detector for DBS
- Linkam pressure chamber with temperature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

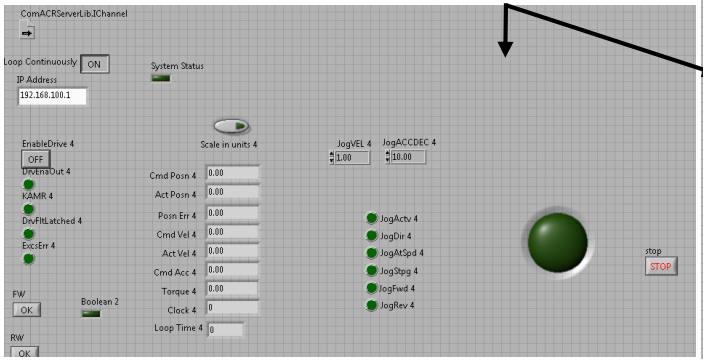

Neutron Imaging
Facility BT#5

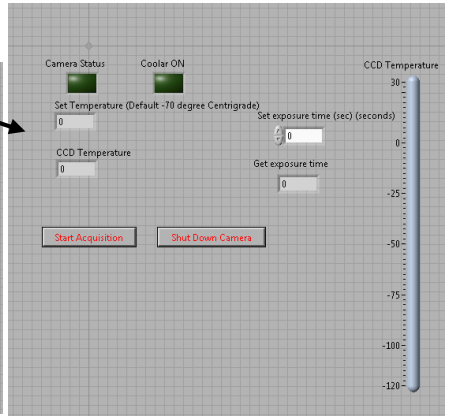
Thermal Neutron Imaging

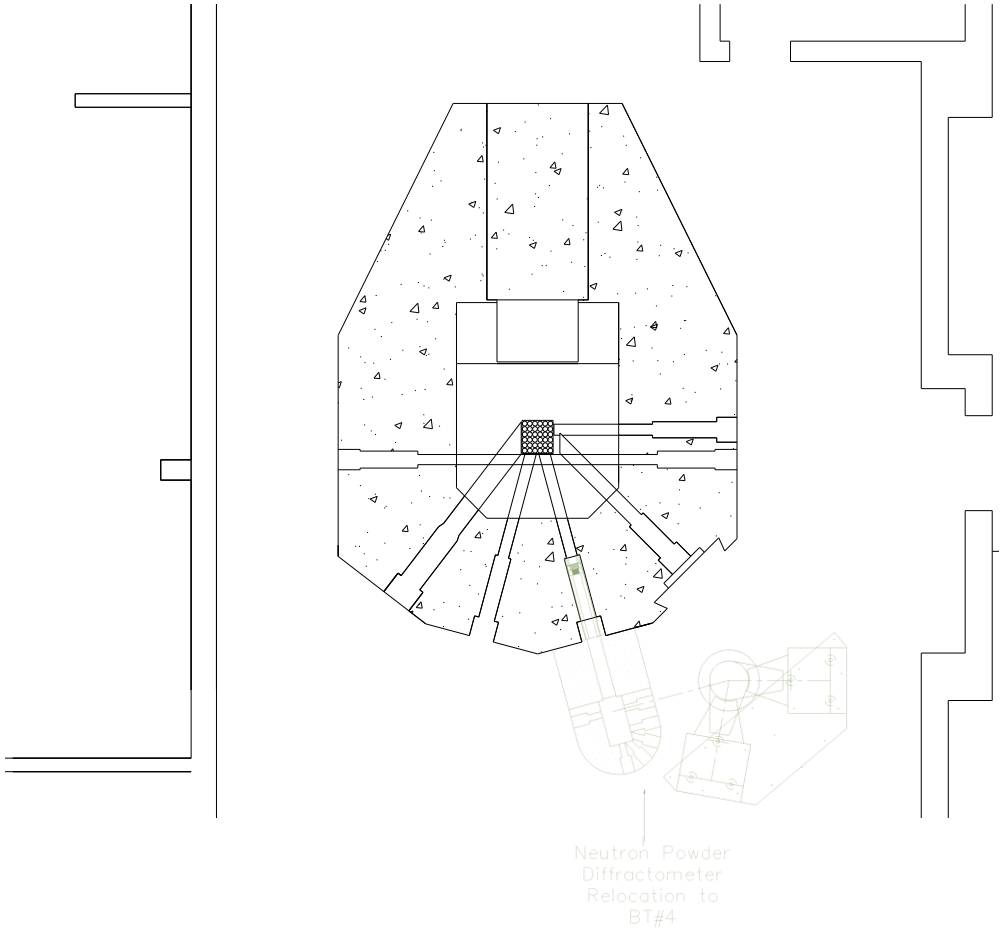




CCD Camera and Tomography Controller LabView Interface

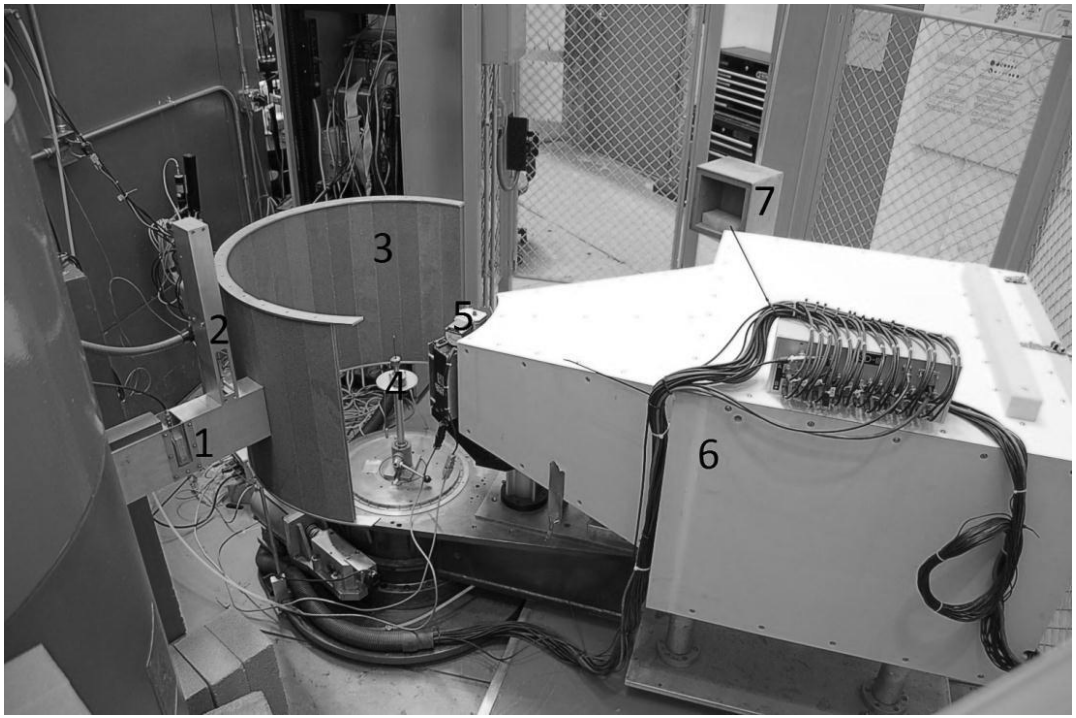


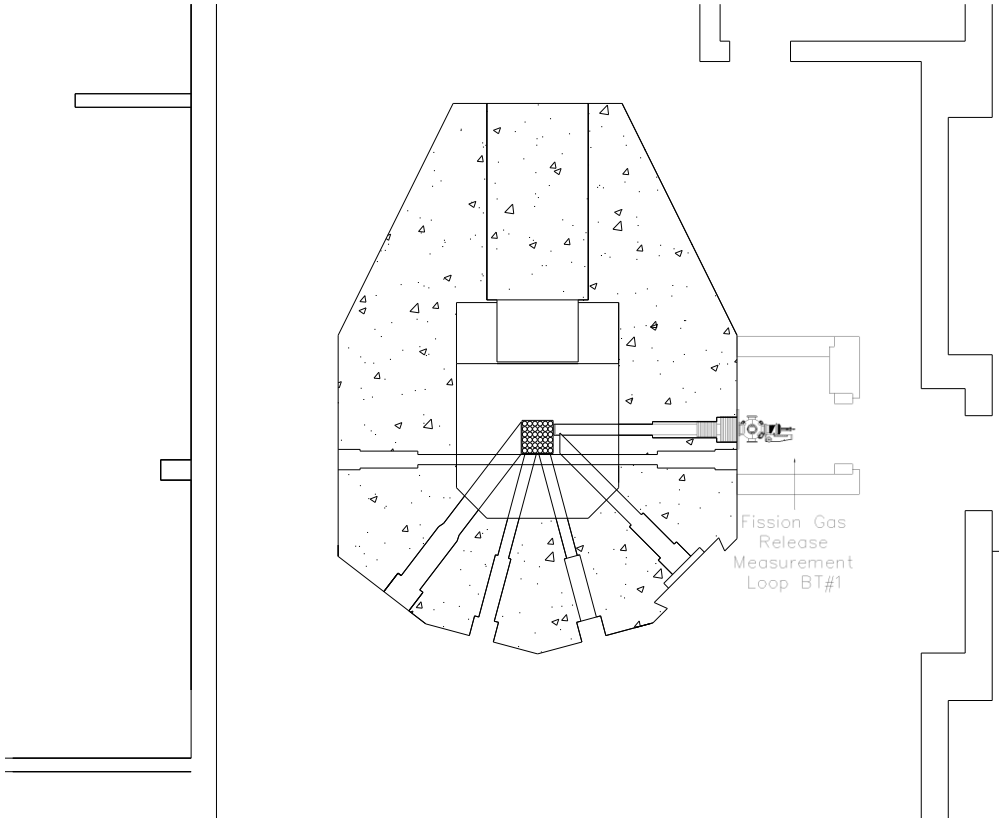



Neutron Powder
Diffractometer
Relocation to
BT#4

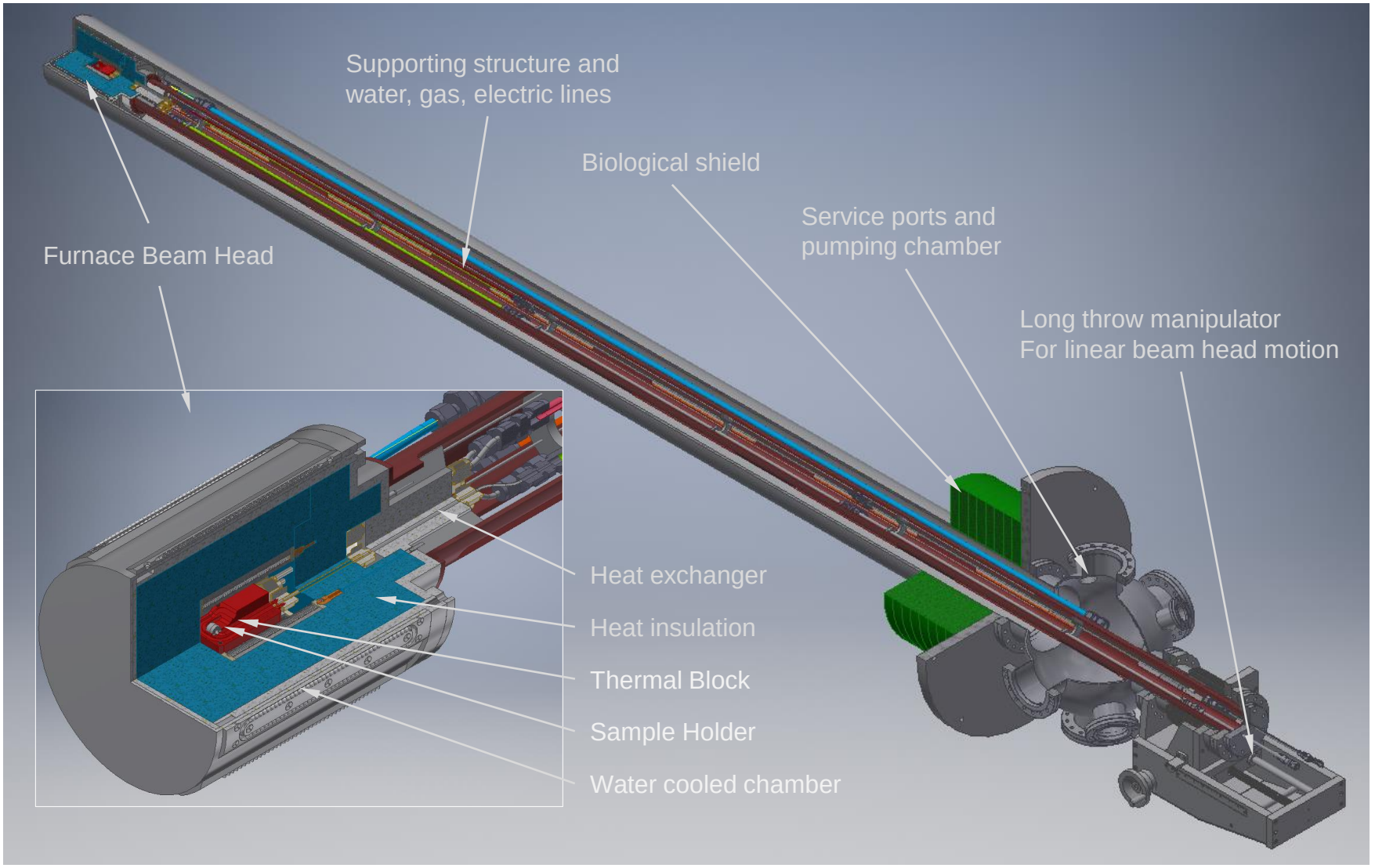
PULSTAR Powder Diffractometer

- 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.




Fission Gas
Release
Measurement
Loop BT#1

FGR Measurement Facility



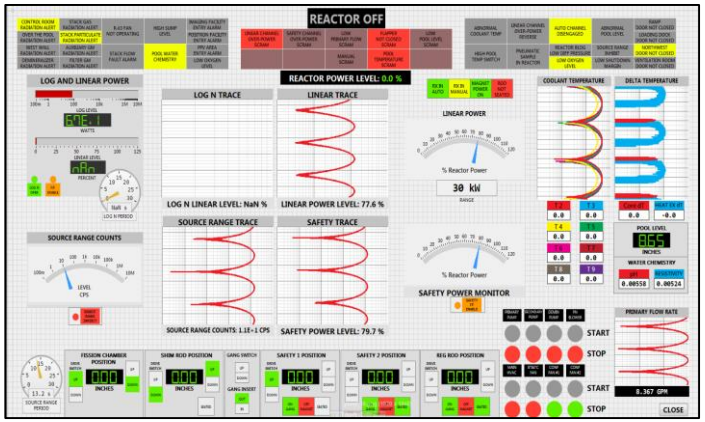
Utilization

- 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

Internet Reactor Laboratory



IAEA's Internet Reactor Laboratory expands access to training

Posted on **January 9, 2017** by **ansnuclearcafe** — **1 Comment ↓**

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.

The White House
Office of the Press Secretary
For Immediate Release

May 24, 2016

FACT SHEET: Enhancing U.S.-Vietnam Civil Nuclear Clean Energy Cooperation

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

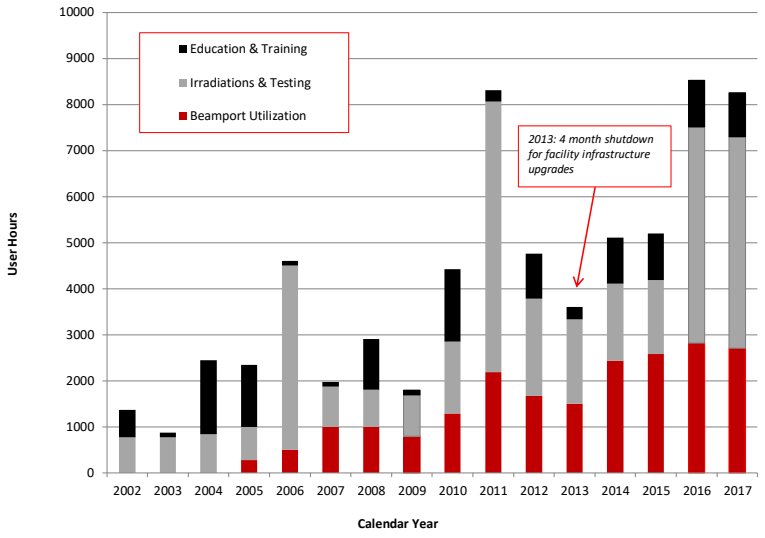
Partnerships

- 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%



Summary

- 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