Supporting Advanced Sensor and Instrumentation Research at the PULSTAR Reactor

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Advanced Sensor and Instrumentation Webinar
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NC STATE UNIVERSITY

Nuclear Reactor Program

UNC System Board of Governors Center

- **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

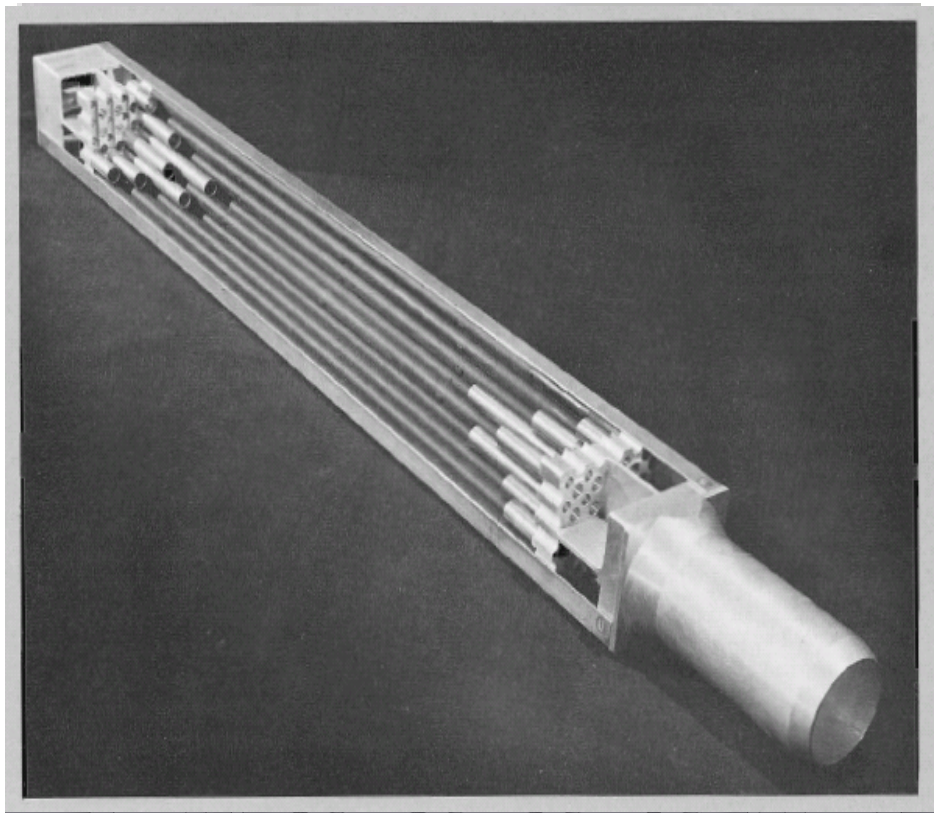
- **Scientific applications and research**
  - Develop state-of-the-art facilities for understanding and applying the principles of radiation interaction with matter
    - Includes in-pool and ex-pool studies

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

NRP NUCLEAR REACTOR PROGRAM

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

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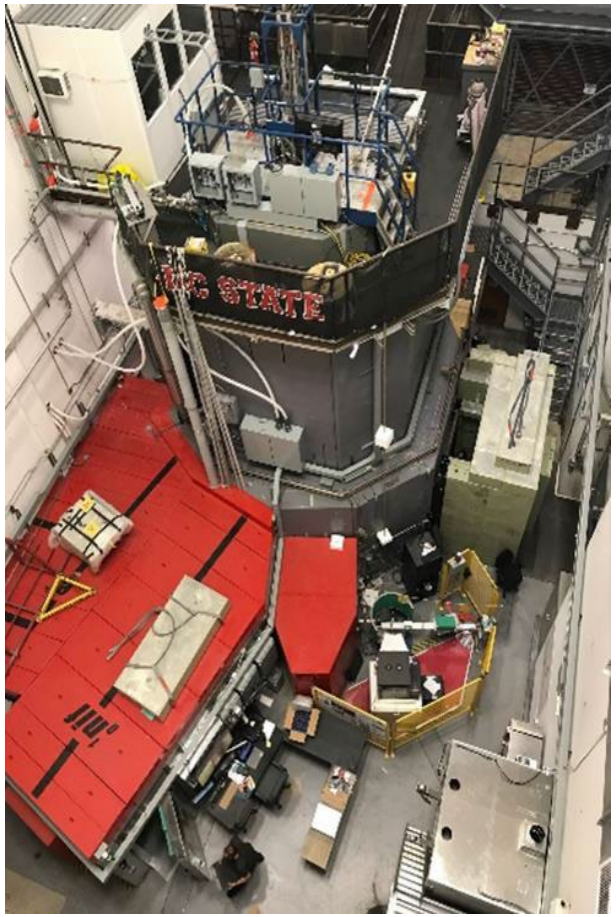
Capability Development

- **Power upgrade** (ongoing)
  - Enhance neutron flux at all irradiation locations
- **License new fuel** (LA issued 2016)
  - Ensure long term operation of reactor
- **Multidisciplinary facility**
  - Instrument the reactor to establish capabilities for a wide user base

NRP NUCLEAR REACTOR PROGRAM

Nuclear Reactor Program

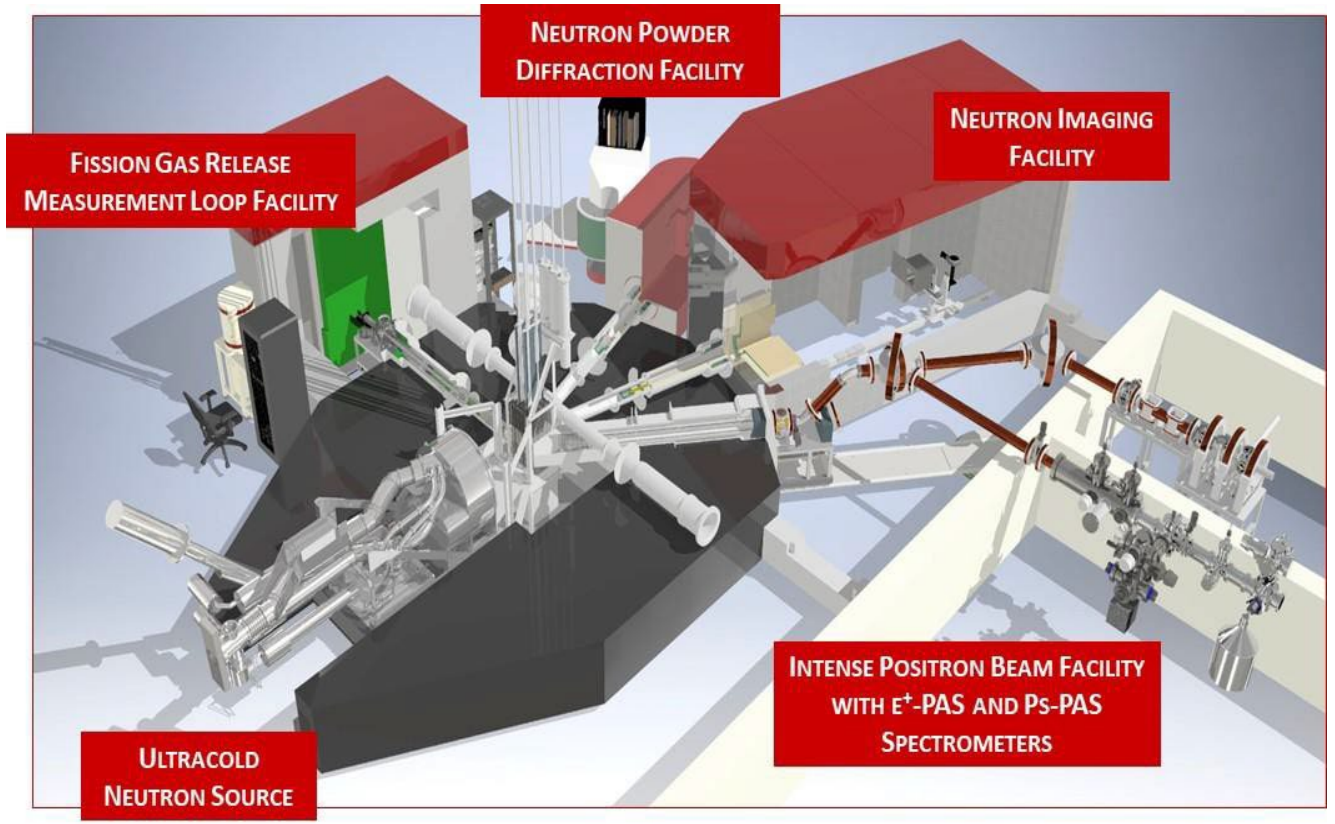
2023



PULSTAR 1-MWth Reactor

DOE NSUF partner

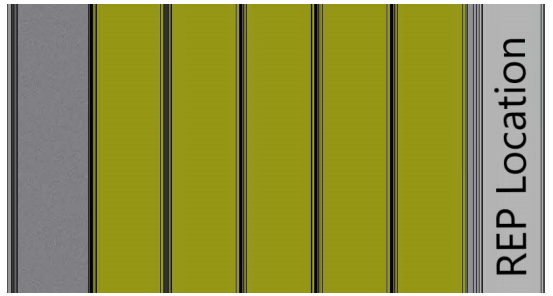
NSF RTNN partner

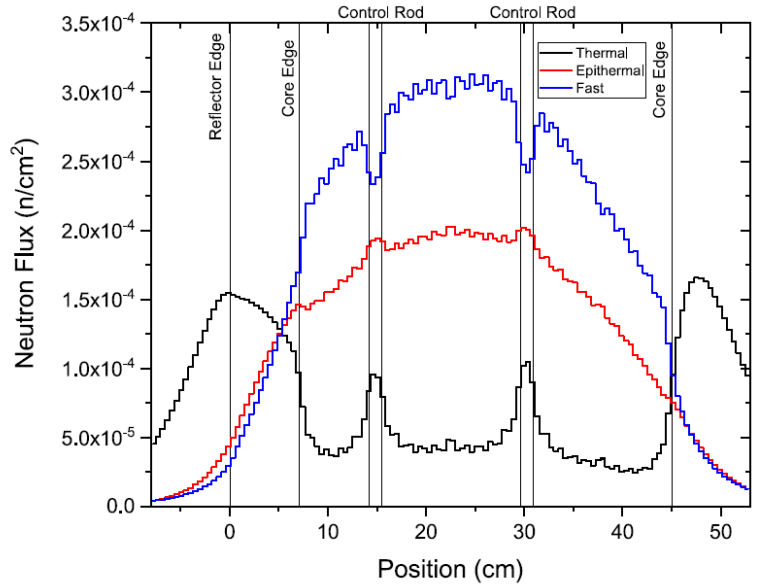


$60M investment in infrastructure

In-Pool Irradiation Facility - REP

- Rotating Exposure Ports (REP):
  - Immersed locations for sealed samples, ID 2.5"
  - Terminates adjacent to east face of core
  - Slow rotation for even sample exposure
  - Cd lined stringers available
  - Max thermal neutron flux: 1.0×10^{13} $n/cm^2/s$
  - Max fast neutron flux: 1.0×10^{12} $n/cm^2/s$
- Typical applications:
  - Bulk NAA for longer-lived isotopes





REP Located in peak thermal flux

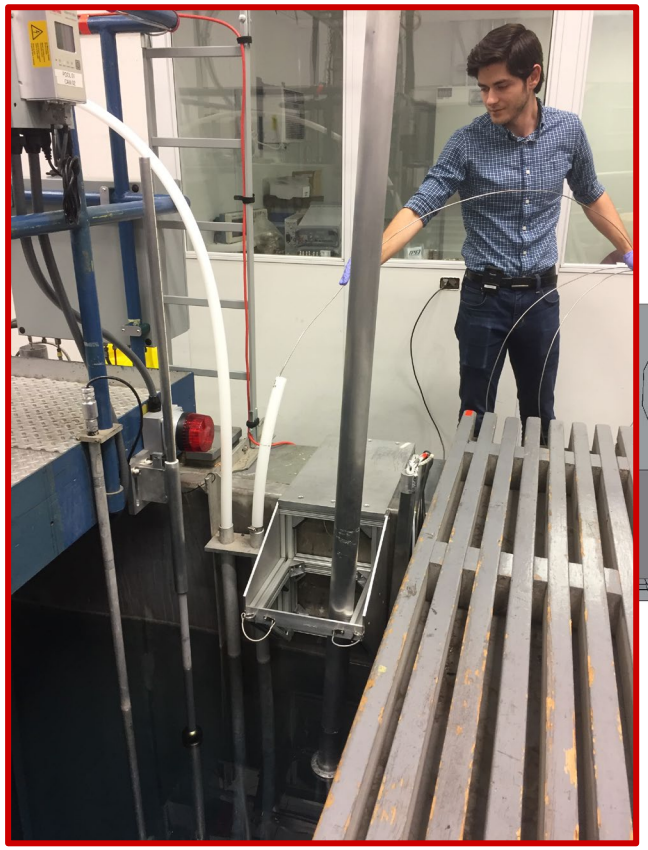
In-Pool Irradiation Facility - DEP

Dry Exposure Ports (DEP):

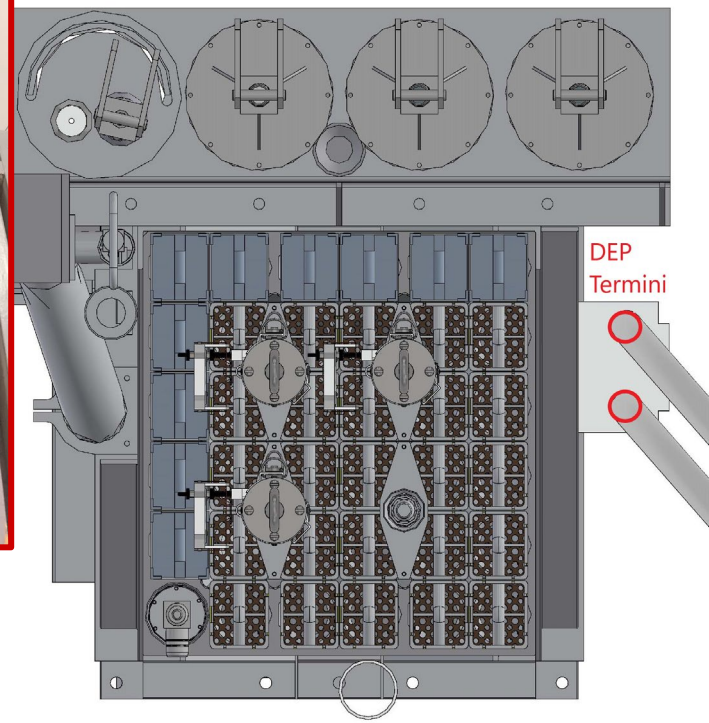
- Easy-in port for small samples, ID 1.25"
- Support for continuous signal cables
- Access to 2 ports via pool top
- Terminates ~2" from north face of core
- Max thermal neutron flux: 4.0×10^{12} n/cm^2/s
- Max fast neutron flux: 1.0×10^{11} n/cm^2/s

Typical Applications:

- Testing of in-core sensors
- Routine sensitivity certification of miniature in-core fission chambers



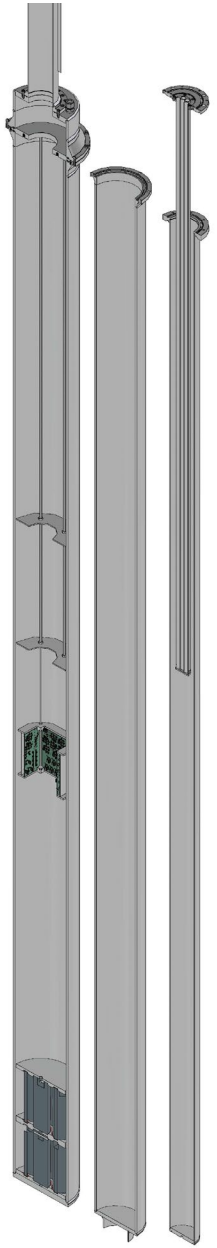
NRP engineer loading a Mirion MIC for sensitivity certification



In-Pool Irradiation Facility - Standpipes

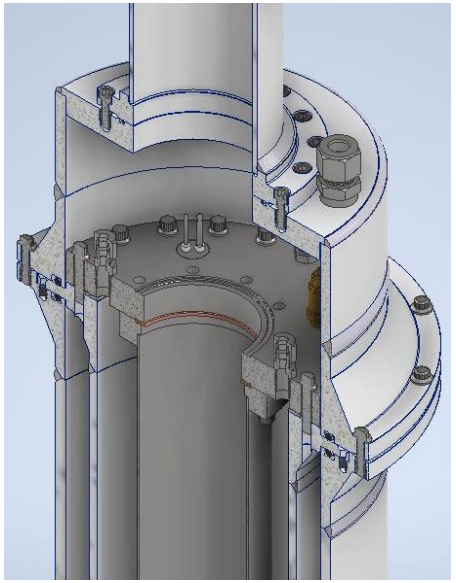
Preparation of SP8-2 for submersion test

- Standpipes:
  - Swapable experiment packages
  - Modular design for custom configuration
  - Max thermal neutron flux: 2.0×10^{12} n/cm^2/s
  - Max fast neutron flux: 4.0×10^{11} n/cm^2/s
- Size Options:
  - SP4 – ID 3.75"
  - SP6 – ID 6.07"
  - SP8 – ID 7.98"
- Umbilical Extensions:
  - UR2.5 (rigid, ID 2.25")
  - UR4 (rigid, ID 3.75")
  - UN2 (non-rigid, ID 2")



Heated Irradiations – Extreme Environment Irradiation Facility

Extreme Environment Irradiation Facility (EEIF):

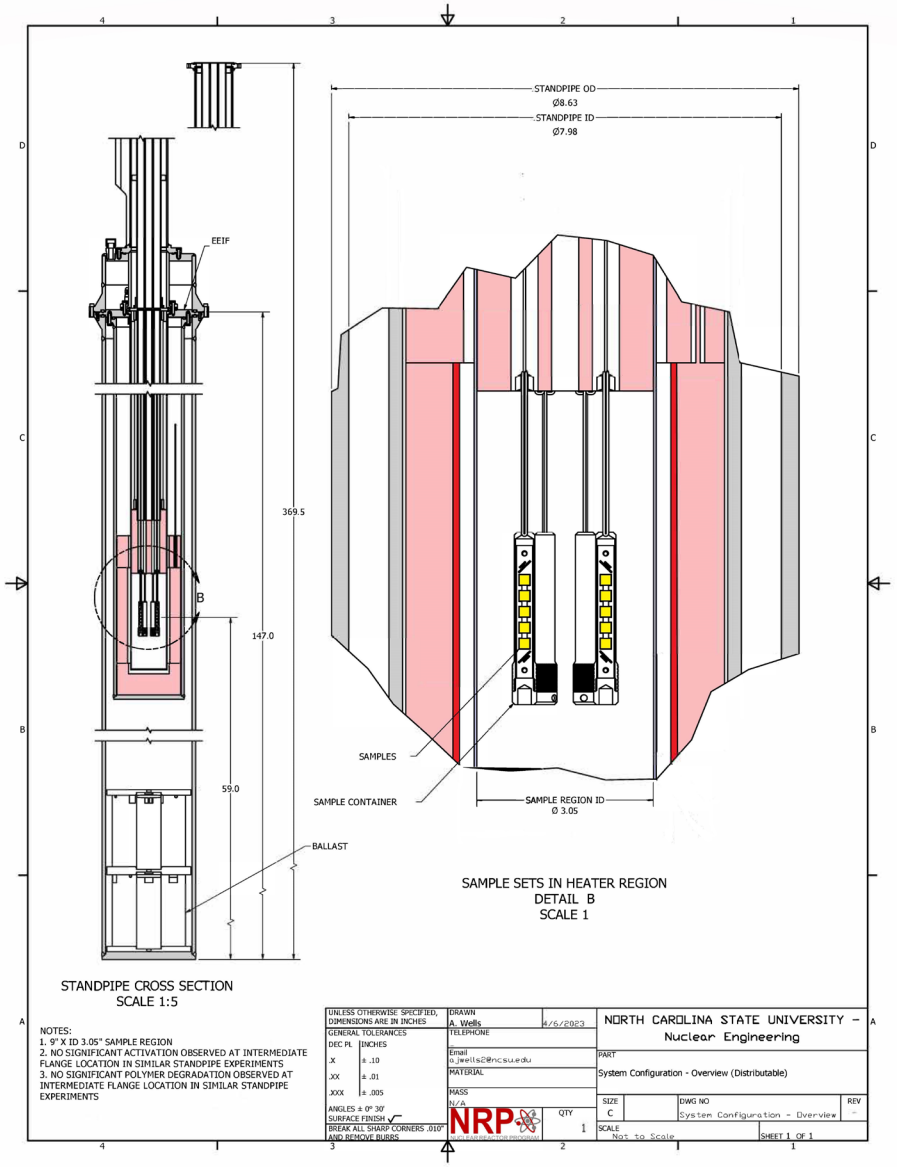


Overview:

- SP8-B84-UR4 module
- Samples up to 9" x 3.00" OD
- Online sample loading/offloading
- ISO 3669 DN75CF experiment port

Design Specification:

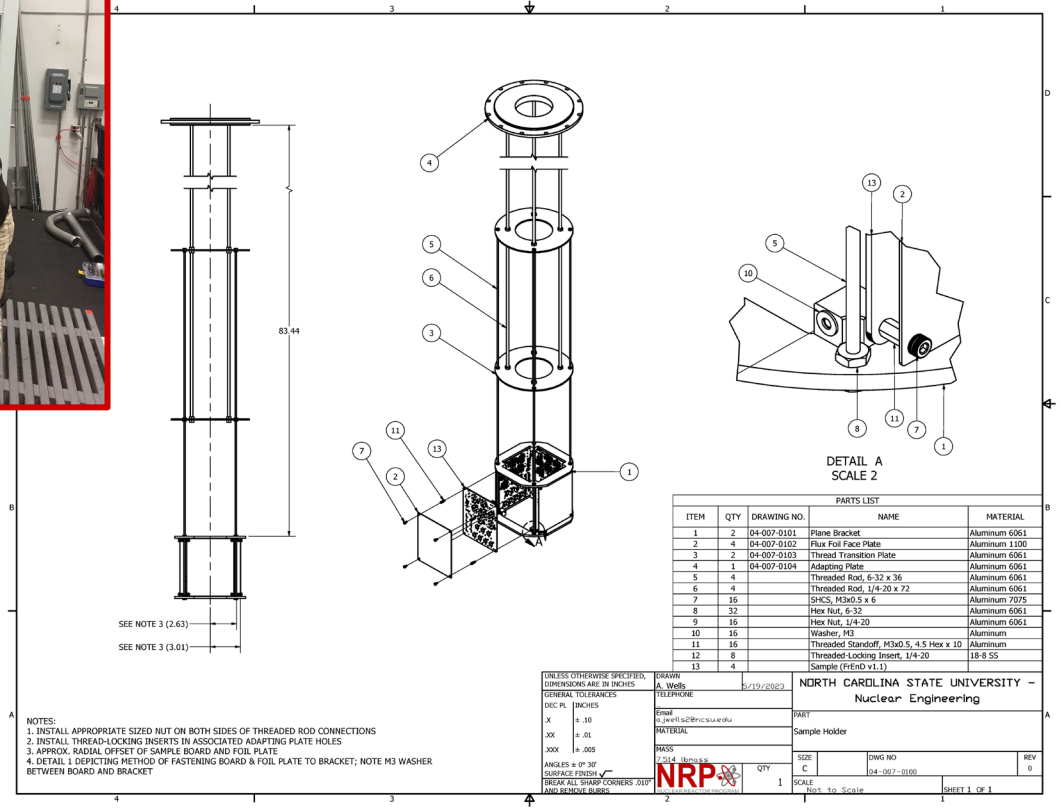
- Max Neutron Flux: $2.0 \times 10^{12}/4.0 \times 10^{11}$ $n/cm^2/s$ (thermal/fast)
- Operating temperatures >800 C
- Inert internal atmosphere options: vacuum, He, or N2



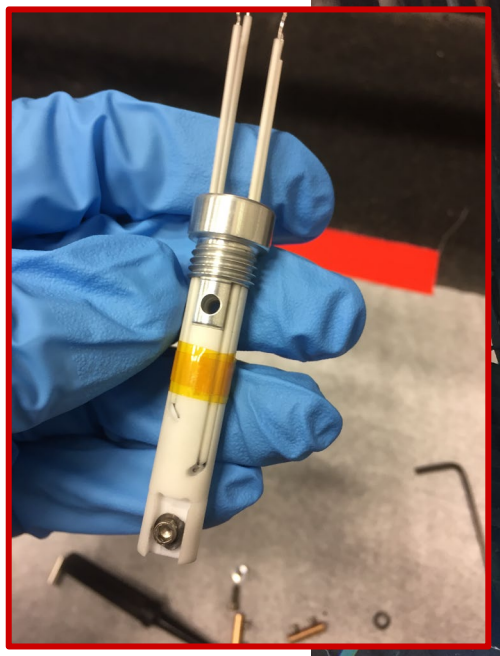
Example – Circuit Board Irradiations

ORNL FrEnD v1.1 (Summer 2023)

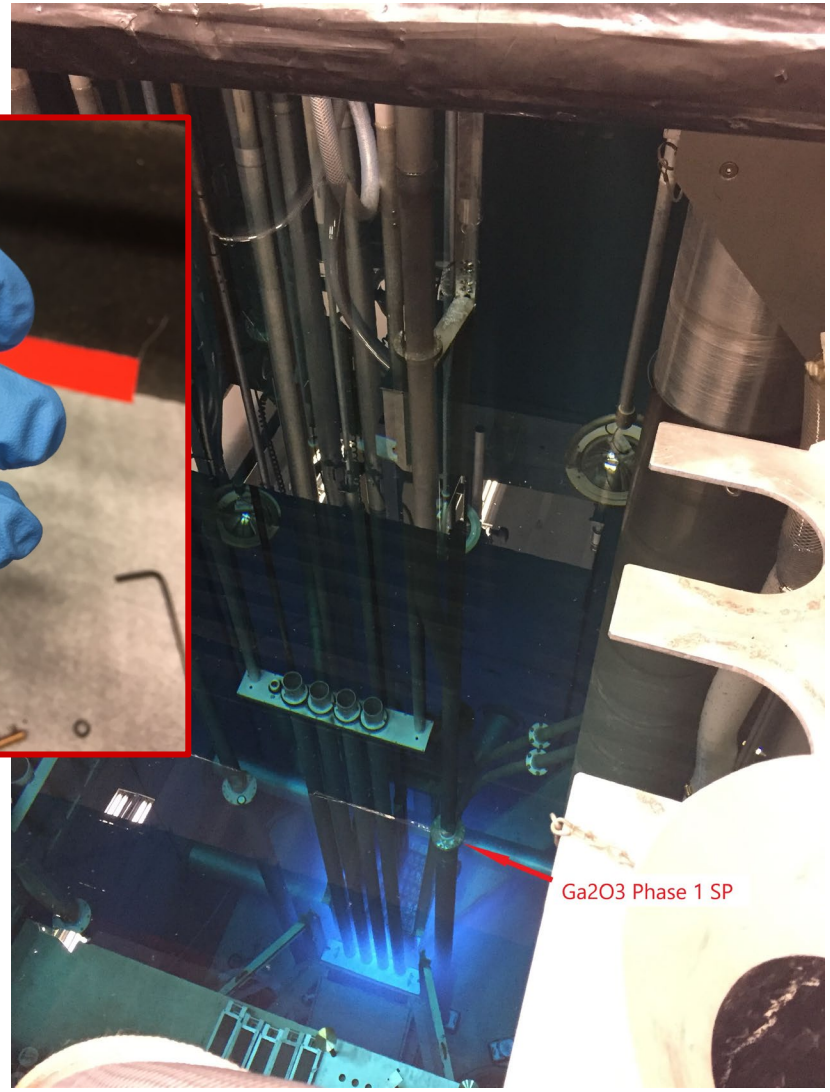
- **NSUF RTE:**
  - Front-end digitizer boards
  - Real-time performance monitoring
  - Non-continuous irradiation, target fluence 10^{14}-10^{15} n/cm^2
- **Facility Configuration:**
  - SP8-B84-UR2.5
  - Custom board array
  - Flux on sample adjusted using Linear Stage – North (LS-N)
  - LS-N permitted acceleration of exposure in later stage of irradiation



Example – Irradiation of Ga2O3 Sensor Material



Alumina sample holder developed for real-time electrical monitoring (fit test prior to final integration)



NSUF CINR - Ga2O3 Crystals

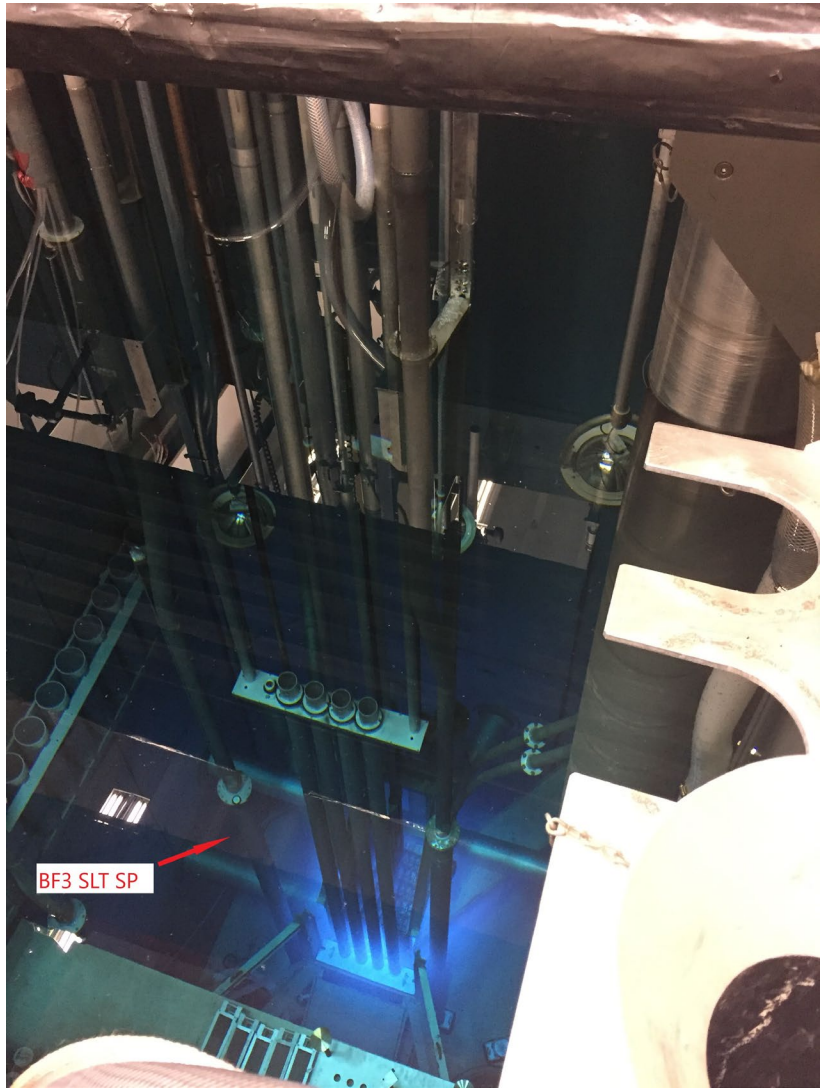
Overview:

- Study behavior of Ga2O3 in strong radiation environment at elevated temperatures
- 2 Phases: ambient (winter 2023) and high temperature (planned winter 2024)
- Tiered exposure up to $1x10^{18}$ n/cm^2 (thermal)
- Post-Irradiation Examination at NCSU positron facility, INL, and CAES
- Optional real-time monitoring of material electrical properties

Facility Configuration:

- Ambient Temperature: SP4-UR2.5 (pictured)
- Elevated Temperature: EEIF

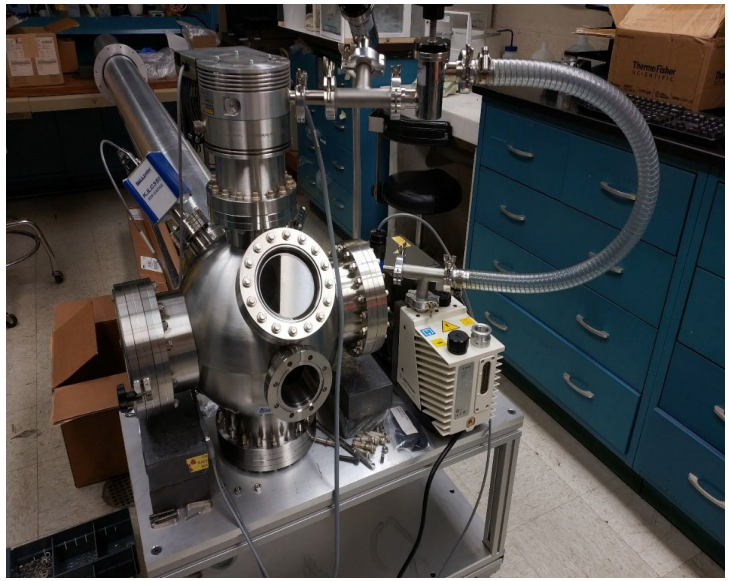
Example – BF3 Detector Accelerated Service Life Testing



Accelerated SLT for Mirion BF3 Detectors (Fall 2022)

- Description:
  - 100 hr Continuous irradiation of BF3 detectors at 1.0×10^{10} n/cm^2/s
  - Rapid (<30 min) post-irradiation performance testing in certified low-flux apparatus
  - Fluxes certified using NRP and Mirion standards
- Facility Configuration:
  - SP4-UR2.5
  - Multi-position detector holder

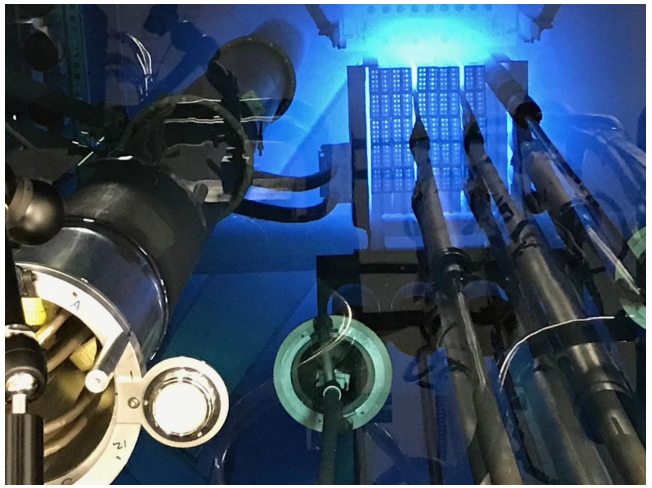
Nuclear Fuel Testing Facility

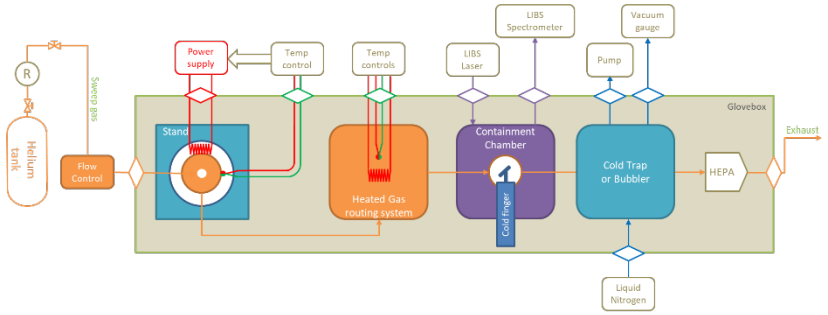


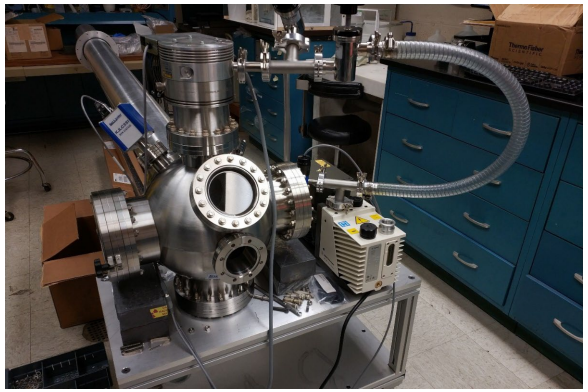
- Measurement of fundamental parameters driving fission gas release from nuclear fuel.

Development of Molten Salt Testing Capabilities

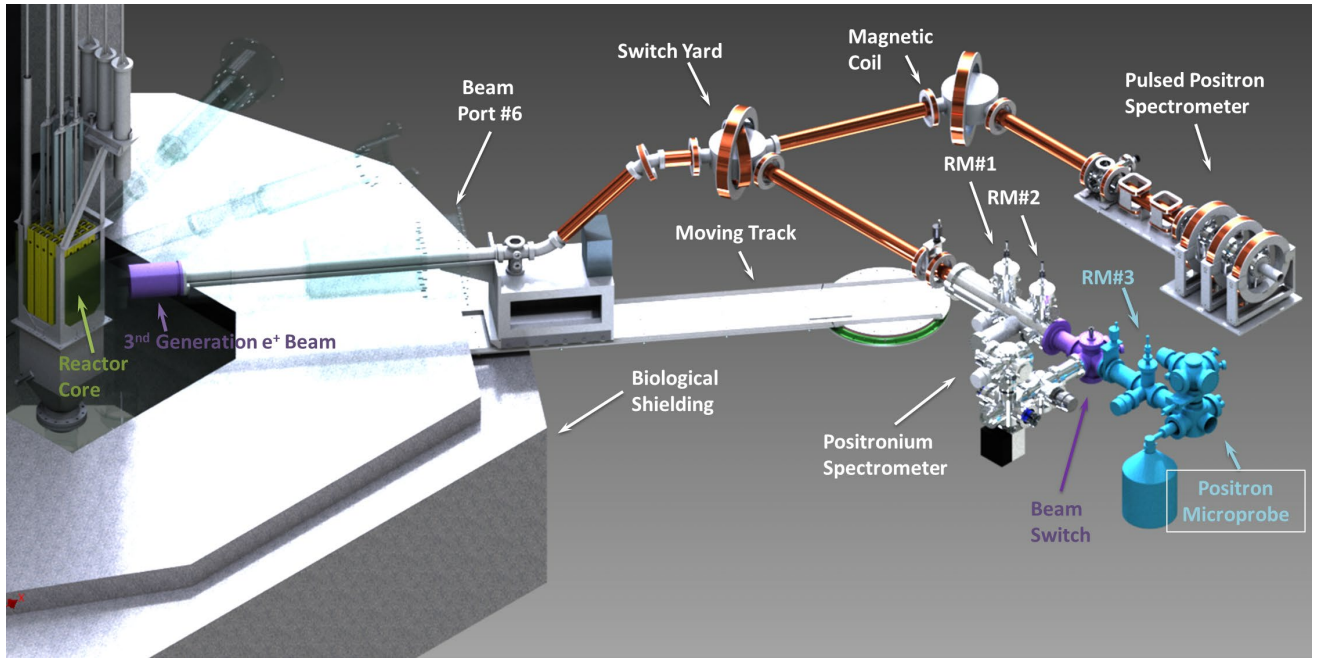
- Molten Salt irradiation Labs and facilities



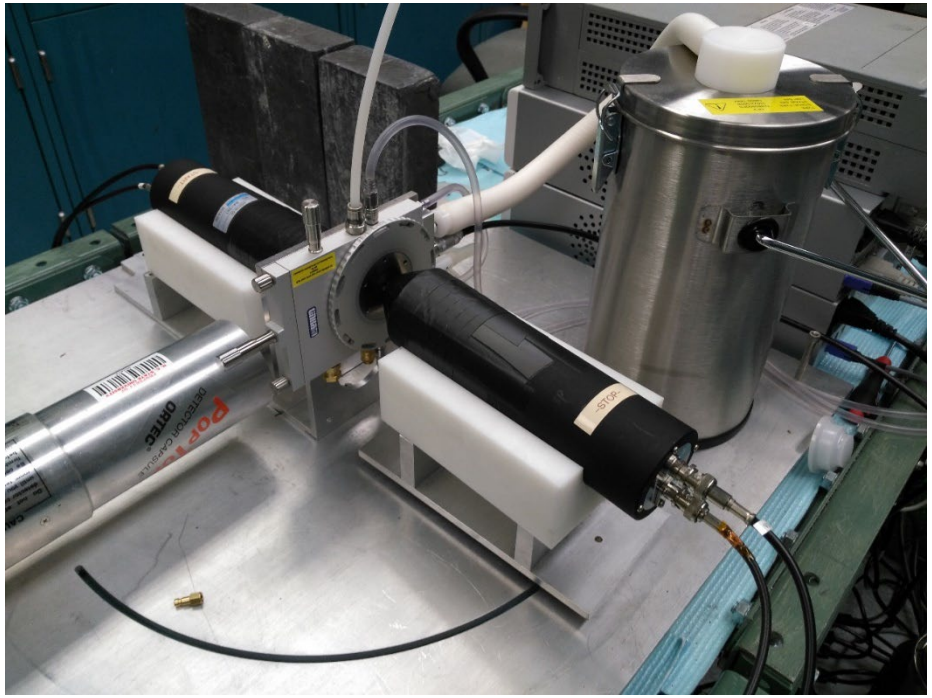




Intense Positron Beam Facility



- Greater than 10^8 e+/s
- Defect analysis on soft matter, semiconductors, metals, etc.
- PALS and DBS analysis



Neutron Scattering – Powder Diffraction

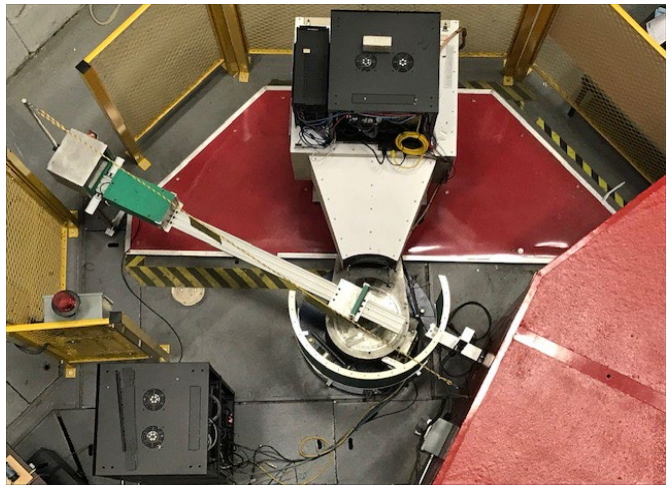
NPDF Facility Upgrades – Dual Purpose:

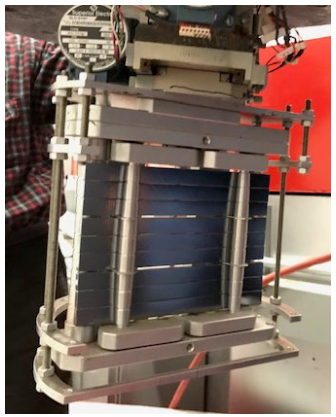
- **Diffraction Measurements:**

  15 New Position Encoding Modules (PEM) – improved diffraction measurement resolution $\Delta d/d$ of 2.9×10^{-3} for ϕ3mm holder

- **Transmission Measurement Capabilities:**

  - Monochromator capable of providing beam wavelengths of 1.085 Å, 1.180 Å, 1.479 Å, and 1.762 Å
  - Transmission Detection Apparatus with collimator.





Summary

- The NC State PULSTAR reactor is a user-oriented facility
  - Versatile irradiation capabilities
  - State-of-the-art analytic instruments
  - Experiment design support (planning, engineering, health physics)
  - User guides and reference documentation
  - Continually upgrading facilities and capabilities
    - Molten Salt Laboratory
    - Fuel Test Facility
    - 2 MW Upgrade

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Thank You

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