Nuclear Energy Research Brookhaven National Laboratory

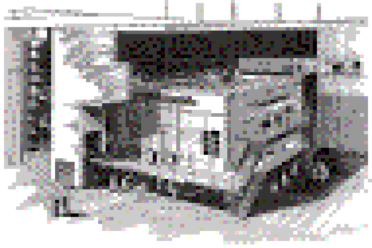
William C. Horak, Chair

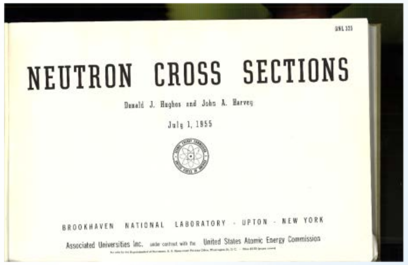
Nuclear Science and Technology Department

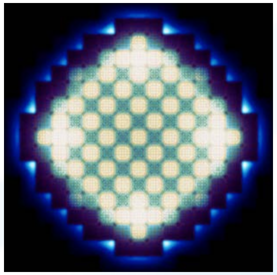
BNL Nuclear Energy Research

- Brookhaven Graphite Research Reactor - 1948
- National Nuclear Data Center - *1952**
- High Flux Beam Reactor - 1964
- Technical Support for NRC - 1974*
- International Nuclear Safety Program - 1986*
- Accelerator Transmutation of Waste - 1991*
- Generation-IV Reactors - 1996*
- Advanced Nuclear Fuels*
- Materials in Radiation Environments*

* Continuing program within NS&T Department

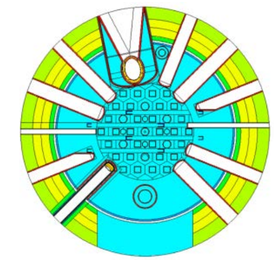


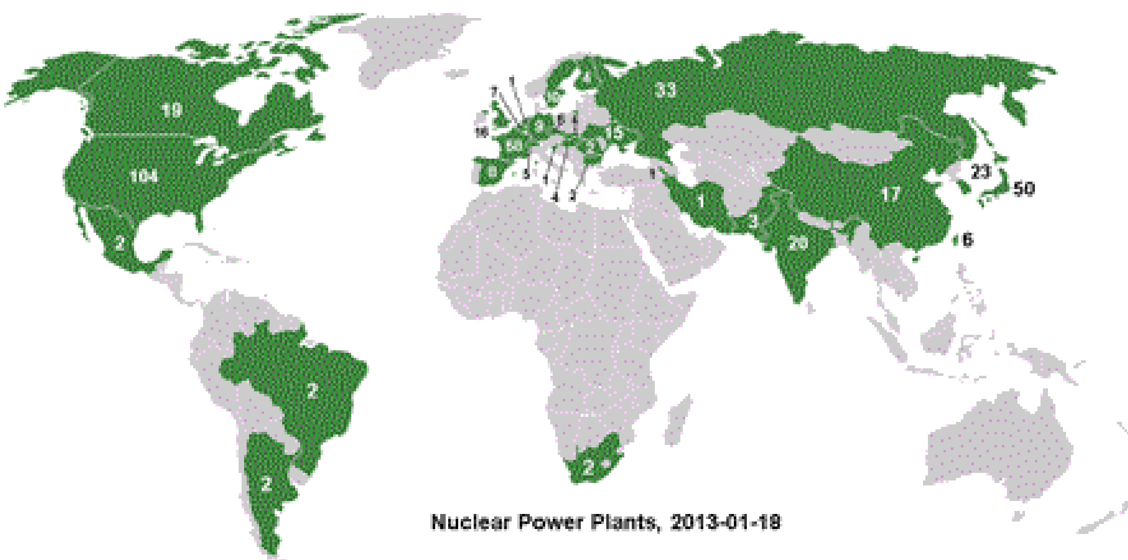


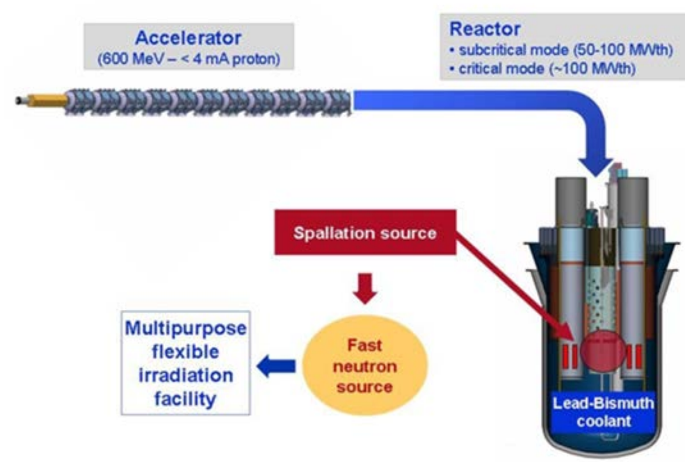


Nuclear Energy Today

- 435 Operable Power Reactors, 12% electrical generation (100 in US, 19%)
- 72 Power Reactors under Construction (5 in US)
- 247 Research Reactors (43 in US)
- ~2 Accelerator-Driven Systems
- ~90 Fusion Test Facilities (2 major in US)

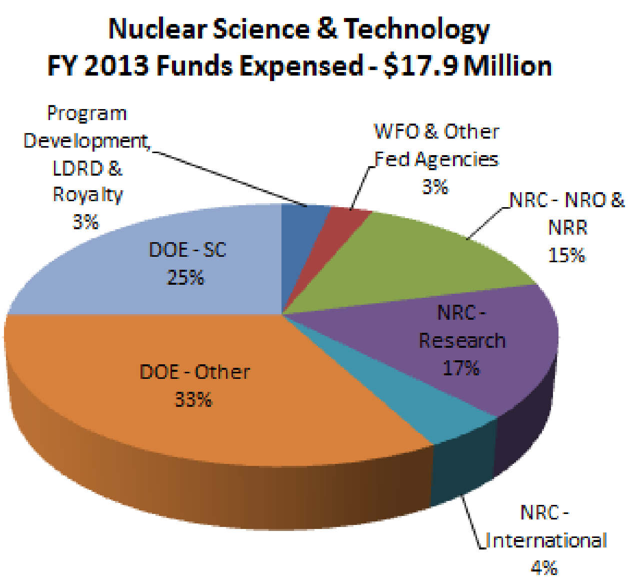






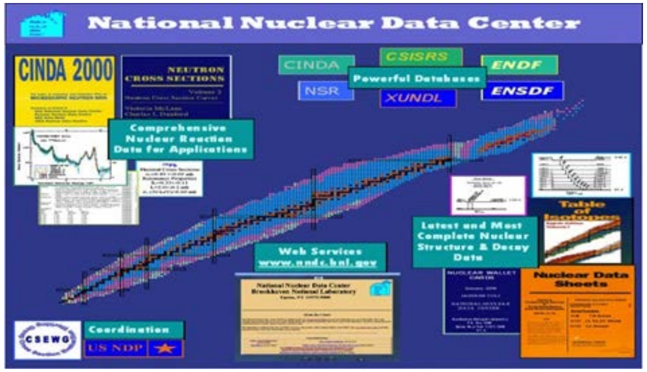
Nuclear Science and Technology Department

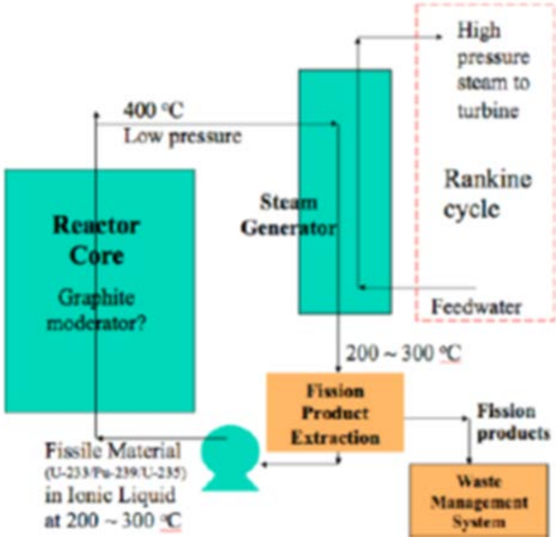
- 55 staff (35 Ph.D.)
- $18 million budget (NRC, DOE-NE, DOE-SC, DOC)
- Building 817
- Manage User Facility–NNDC
- Facilities–NSLS, NSLS-II, CFN, BLIP,CARIBU (ANL)



Main Research Areas

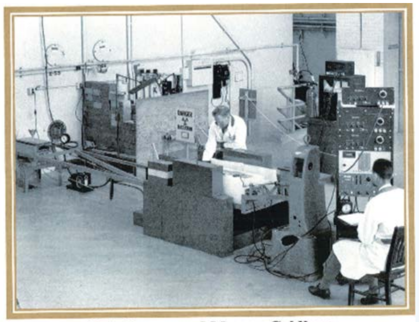
- National Nuclear Data Center
- Nuclear Safety
- Advanced Nuclear Systems
  - Radiation Resistant Materials
  - Accident Tolerant Fuels
  - Generation-IV Reactors
  - Accelerator-Driven Systems





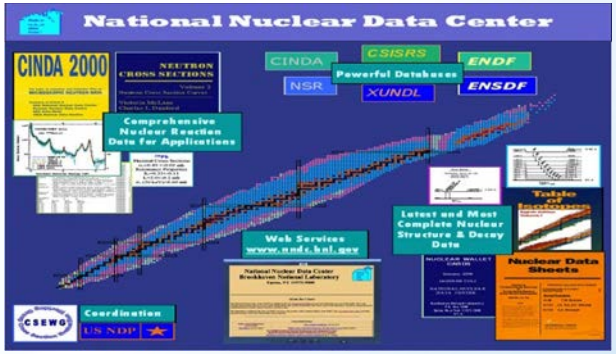
National Nuclear Data Center

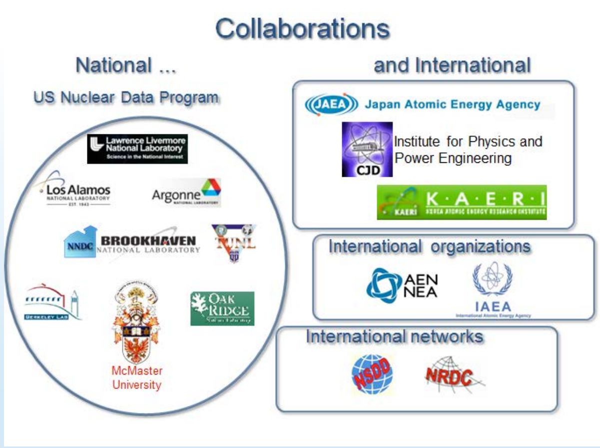
- Longest continuing program at BNL
- Funded by Office of Nuclear Physics
- National User Facility–“an essential national resource”
- Lead for US Nuclear Data Program
- Provide nuclear data sets for research, medical, industrial, nuclear energy and national security applications.



Jack Harvey and Murrey Goldberg

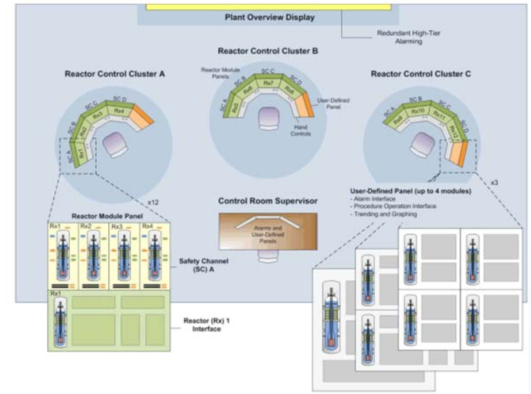
1955

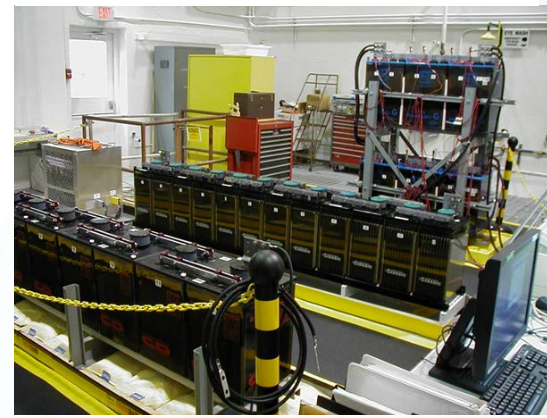


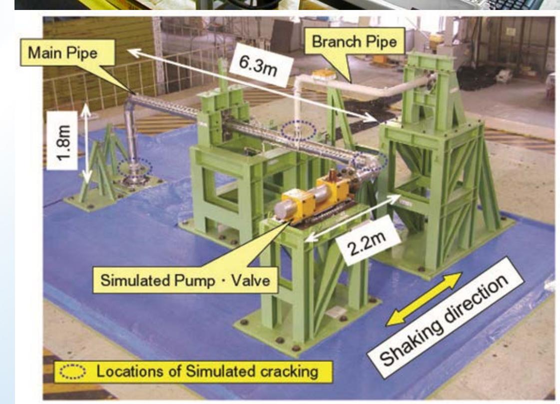


Nuclear Safety

- NRC
  - Simulations and Analyses
  - Human Factors
  - Battery Test Facility
  - Seismic Test Facility (Japan)
- Research Reactors
  - National Institute of Standards and Testing Reactor
  - University Reactors
- Post-Fukushima Programs
  - R. Bari on National Academy panel on Fukushima accident
  - Review of Seismic and External Events for US Plants
  - Battery Life Extension

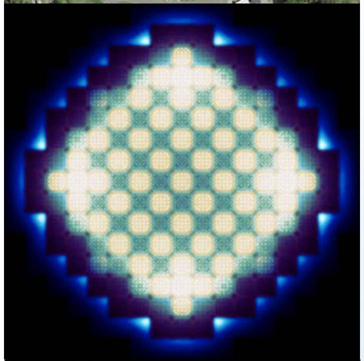


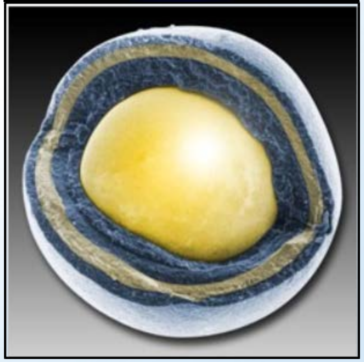


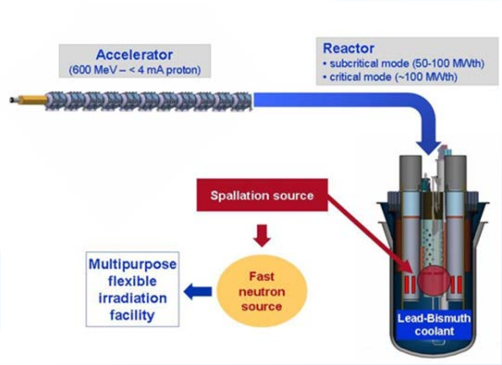


Advanced Nuclear Systems

- Materials in Radiation Environments
- Fuel Cycle Research and Development
  - Fuel Cycle Options Study
  - Accident Tolerant Fuels
  - Thorium Fuel Cycles
- Alternative Reactor Designs
  - Ionic liquids
  - Accelerator-Driven Systems







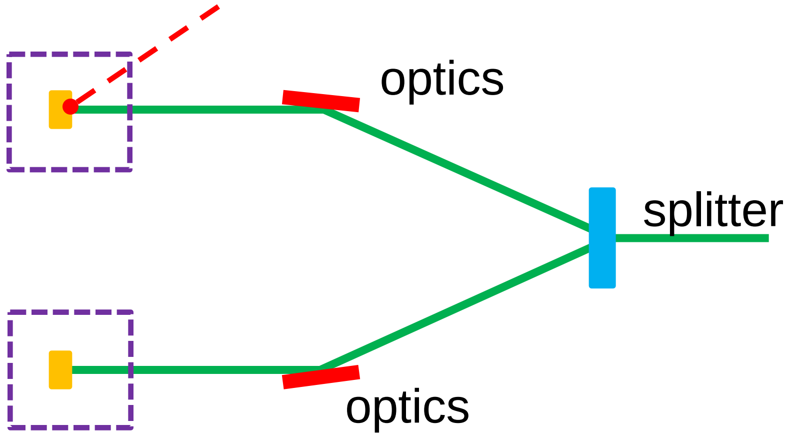
Materials in Radiation Environments

- Special Cell for NSLS-II Endstation for Supercritical CO_2
- Nuclear Energy Enabling Technology Awards
  - Automated Synchrotron X-ray Diffraction of Irradiated Materials
  - Advanced Coatings for Advanced Reactor Fuels and Structural Materials
- First Light Experiment at NSLS-II
- Materials in a Radiation Environment Beamline

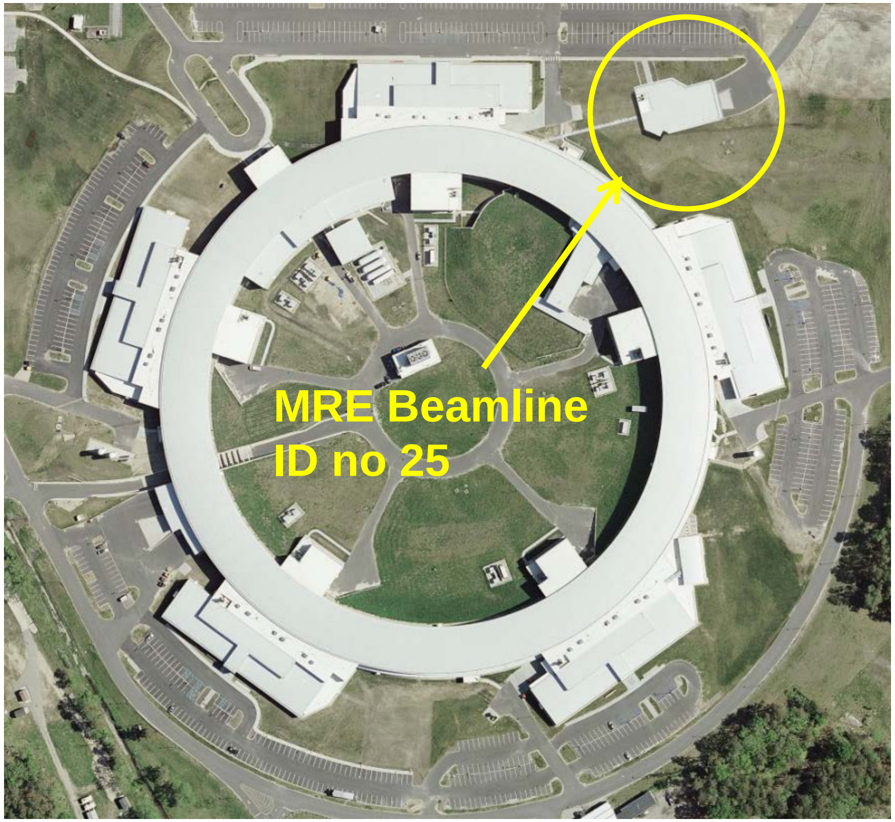
National Synchrotron Light Source–II Beamline for Real Time and In Situ Studies of Materials in a Radiation Environment (MRE)

MRE is located in separate buildings and will provide two unique capabilities:

Station 1: In situ studies of radiation damage with particle beams



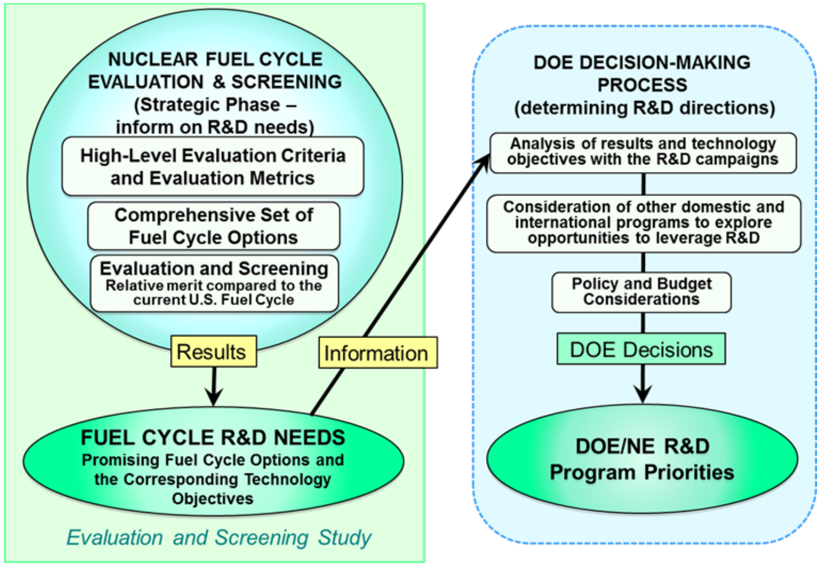
Station 2: Characterization of more highly radioactive materials than are currently allowed at US synchrotrons (compatible with INL-IMCL)



MRE has national (LANL, INL, UCSB, UCB and ORNL) support and a large user community. It was approved by Science Advisory Committee, NSLS-II 2013.

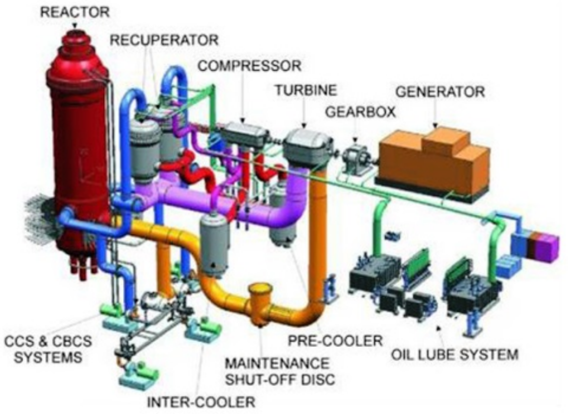
Fuel Cycle Research and Development

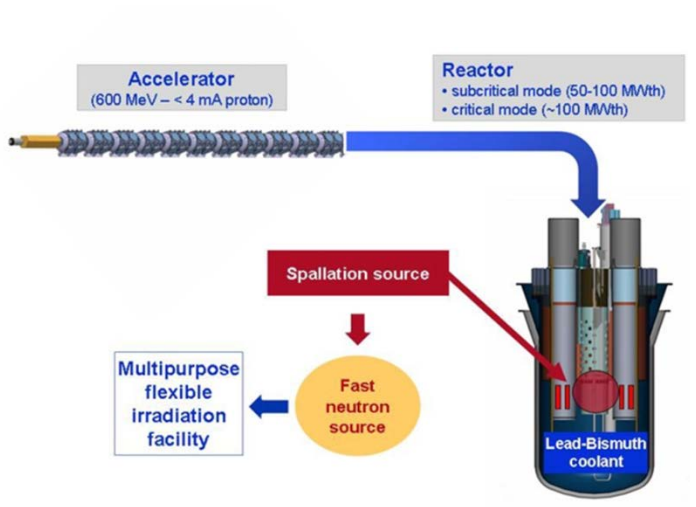
- Reviews of Advanced Fuel Cycles
  - Advanced Nuclear Cladding and Fuel Materials with Enhanced Accident Tolerance for Current Generation & Generation III+ Light Water Reactors (2012)
  - Evaluation & Screening of Fuel Cycle Options
- Advanced Fuel Development
  - Thorium Fuel Cycles
  - Silicon Carbide
  - Metallic Fuels
  - Matrix Fuels



Advanced Nuclear Systems

- System Reviews
  - DOE-NE Advanced Reactor Concepts
  - DOE-SC Accelerator and Target Technology for Accelerator-Driven Transmutation and Energy Production
- Ionic Liquid Reactor
  - Passive Safety Features
  - Improved Waste Management
  - Proliferation Resistant
  - Reduced Costs
  - Rapid Load Following
- Accelerator-Driven Systems
  - Waste Transmutation





Leveraging the Two Pillars

Materials in Radiation Environment Beamline

- Unique Facility for Advanced Materials
- Final Design of End Stations
- Beamline Advisory Team has Strong Industry Participation

Advanced Nuclear Systems

- ADS Target/Subcritical Blanket Design
- Ionic Liquid Design (Duke, AREVA)

Nuclear Data

"encouraged to pursue a potential collaboration with BLIP in order to address deficiencies and gaps in the cross section and nuclear structure data for medical isotopes..."

Nuclear Energy Research at BNL 2014-2020

- New Research Capabilities at BNL
  - NSLS-II: Materials in Radiation Environments
  - Accelerator Facilities (irradiation, data measurements)
  - Small Dedicated Facilities (e.g., battery test laboratory)
- National Nuclear Data Center
  - Increase productivity and experimental programs
- Advanced Nuclear Systems
  - Industry collaborations will be key
- Advanced Fuels
  - Accident tolerant fuels
  - Particle fuels
- Nuclear Regulatory Commission projects will remain a major sponsor for nuclear research
  - New Reactor Licensing
  - Life Extension–60+
  - Fukushima Task Force Recommendations
- University Collaborations (twelve projects)
- International Collaborations (IAEA, Japan, South Korea)

Thank you

Automated Synchrotron Studies of Irradiated Reactor Pressure Vessel Steels

Objective: How do phases such as late blooming Ni-Mn-Si rich phases or LBP created by long-term exposure to neutron irradiation effect the fracture toughness of Light Water Reactor pressure vessels? How do various combinations of temperature, flux, fluence and alloy compositions impact these phases?

Importance: The current fleet of nuclear reactors in the U.S. will be seeking license extensions for continued operation from 60 to 80 years. The RPV is prohibitively expensive to replace. Therefore, a more complete understanding of the microstructural and property changes in RPV steels during long-term operation is essential.

Challenges:

- Working with radioactive samples at a synchrotron
- Acquiring data on a statistically significant number of radioactive samples

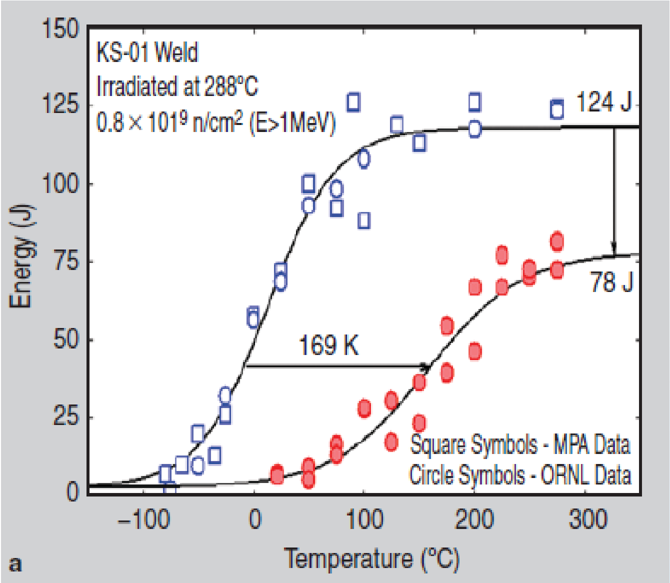
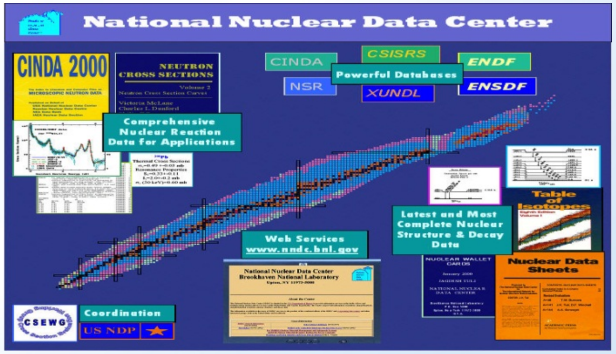


Figure shows the elevation of the temperature regime of brittle cleavage fracture, characterized by Charpy V-notch impact test 41J temperature shifts (ΔT)

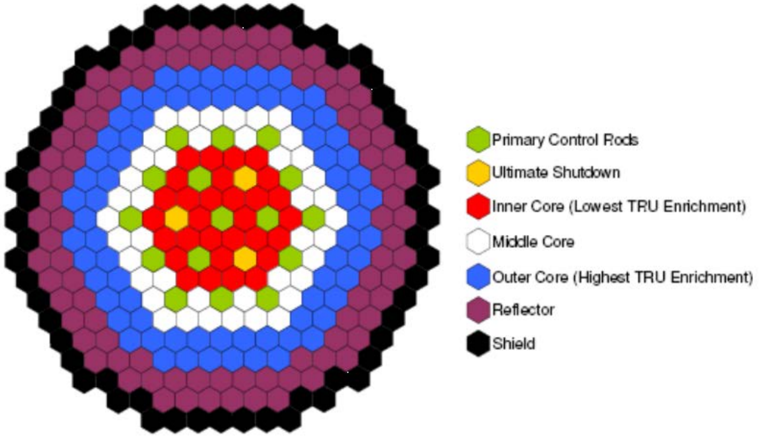
Main Capabilities

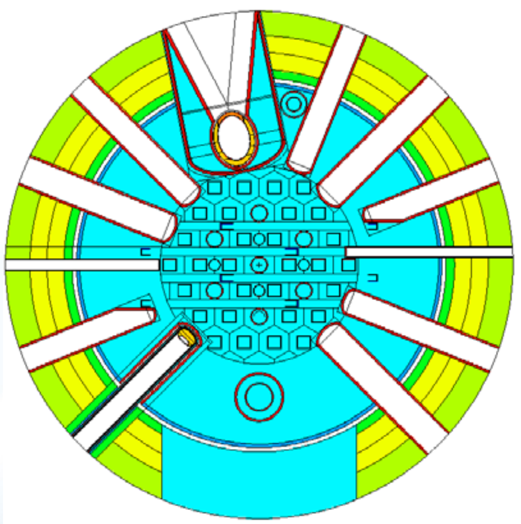
- Advanced Materials
- Nuclear Sciences Analysis
- Structural and Seismic Analysis
- Systems Engineering Group
- Probabilistic Analysis
- National Nuclear Data Center



Reactor Safety Analyses

- Fuel management assessments of light water reactor (LWR) and sodium fast reactor (SFR) options
- Thorium-based options for LWRs
- NIST research reactor (NBSR) neutronics and thermal-hydraulics
  - License renewal safety analysis report
  - Conversion from HEU to LEU





Nuclear Analysis Tools At BNL

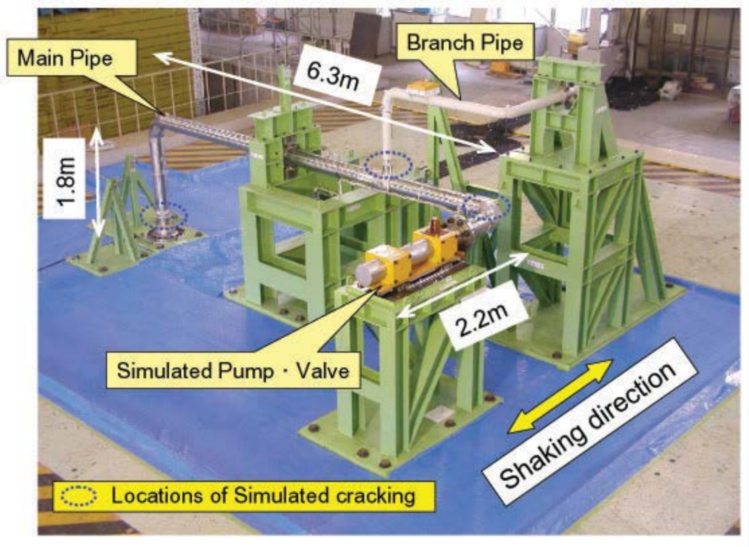
- Lattice Physics
  - TRITON (SCALE 6.1), DRAGON, BOXER, **WIMS**
  - MCNP5, MONTEBURNS, MCNPX
- Core Neutronics
  - DORT, **TORT**
  - REBUS/DIF3D
  - MCNP5/MCNPX
  - PARCS
  - **RELAP-3D**
- Other
  - ORIGEN-S, **NJOY**
- Related capability
  - Familiarity with vendor codes
  - Close relationship with BNL's National Nuclear Data Center

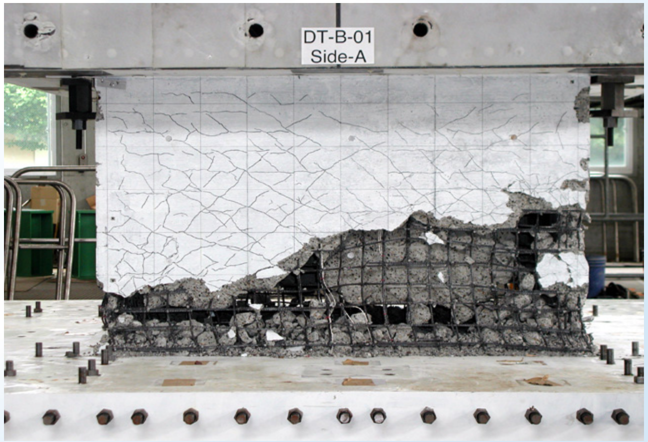
Thermal-Hydraulic Tools At BNL

- T-H-Neutronic coupled codes
  - TRACE/PARCS
  - RELAP5/PARCS
  - **RELAP5-3D**
- Subchannel analysis
  - **COBRA-EN**
- Heat conduction
  - HEATING
- Thermal/Stress
  - ANSYS; LS-DYNA
- Thermo-mechanical
  - **FRAPCON, FRAPTRAN**

Structural and Seismic Analysis

- Large-scale seismic tests conducted in Japan
- Degradation of structures with Korea
- Gen III reviews
  - AP-1000
  - ESBWR
  - EPR

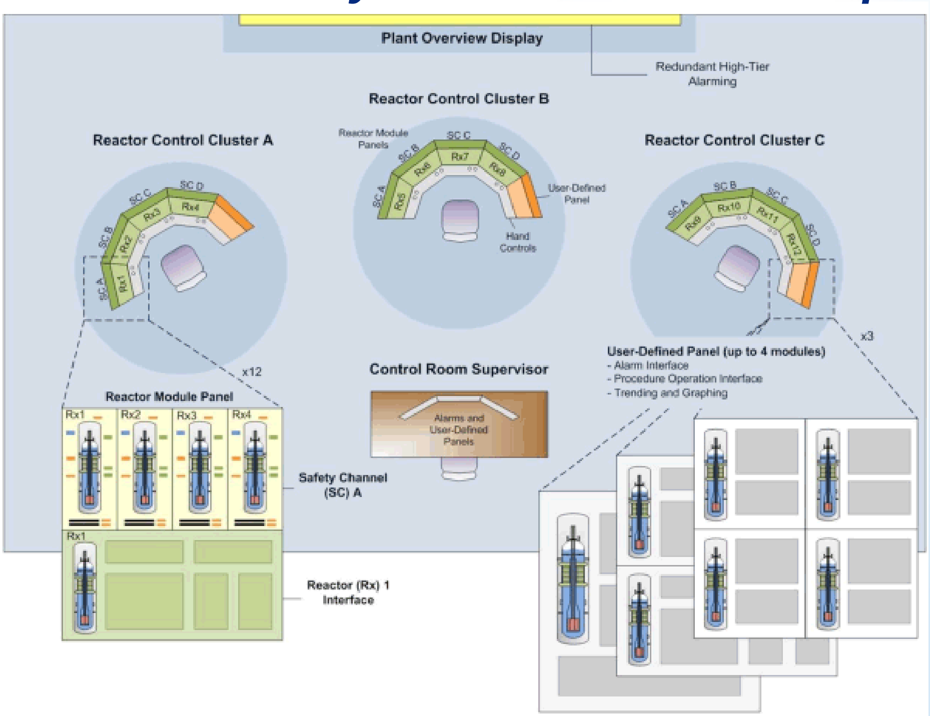




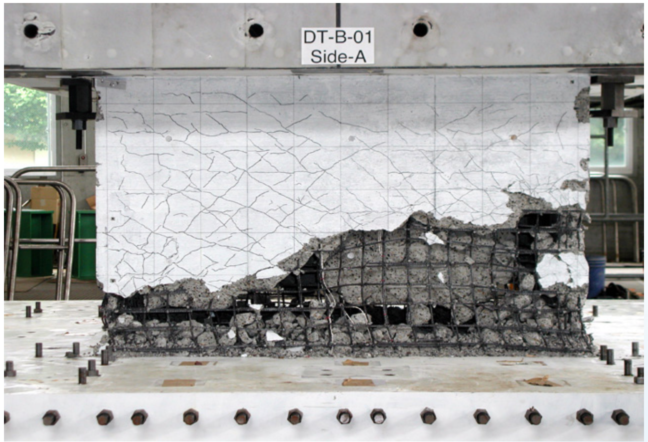
Human Factors: SMR Issues

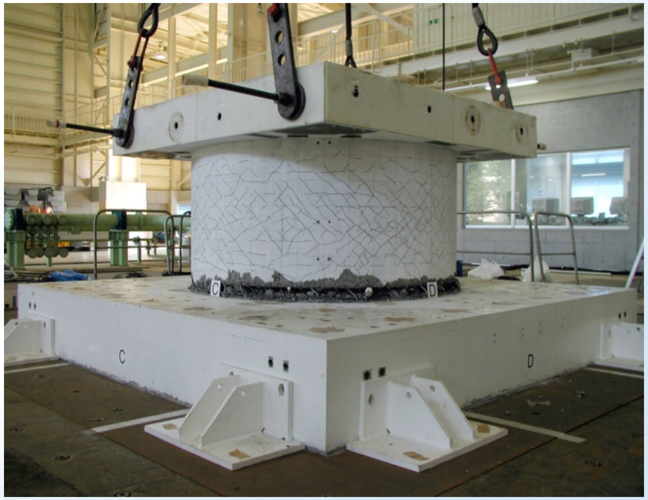
- Impact of Adding Modules During the Operation of Other Modules
- Module/unit Differences
- Multi-unit Situation Awareness
- Control Room Configuration and Workstation Design for Multi-Modular Teams
- HSI Design for Multi-module Monitoring and Control

Preliminary NuScale MCR Concept



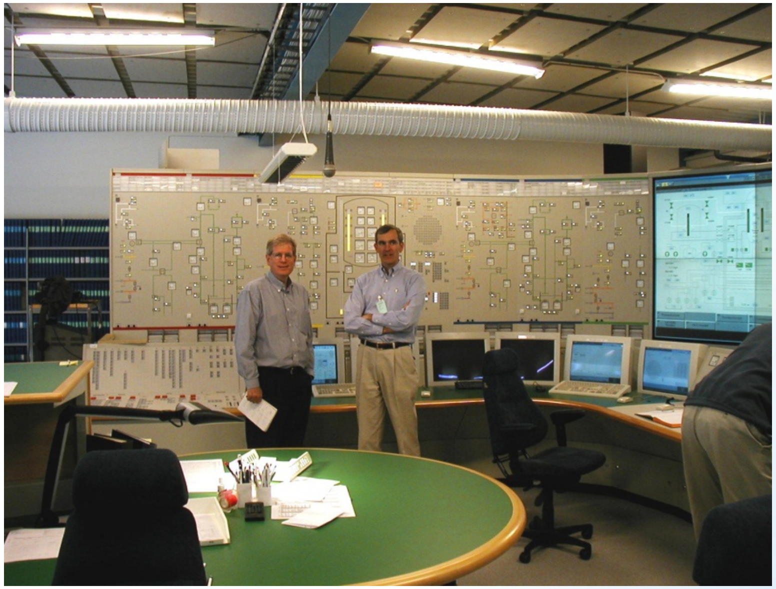
Collaboration with Japan (JNES) on Multi-Axial Loading Shear Wall Tests



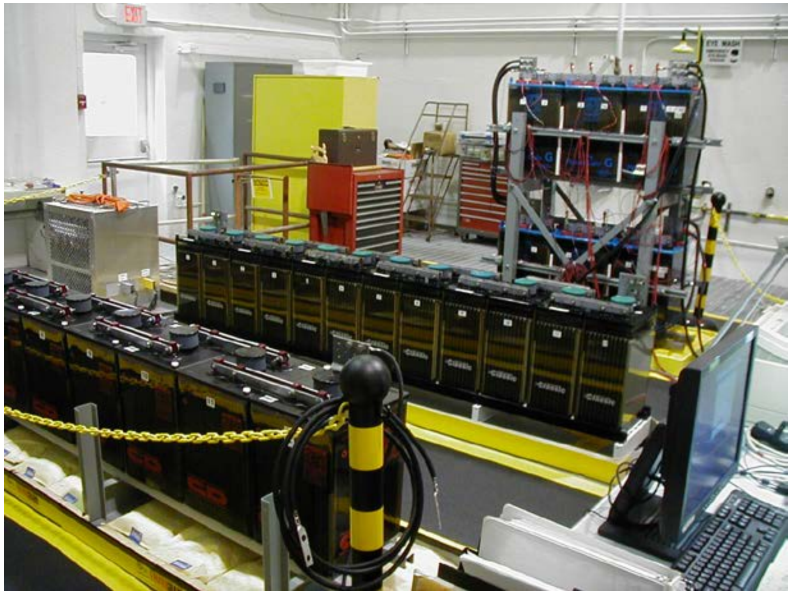


Systems Engineering Group

- Electrical Engineering
- Human Factors, Human Systems Interface
- Nuclear Facility Operations



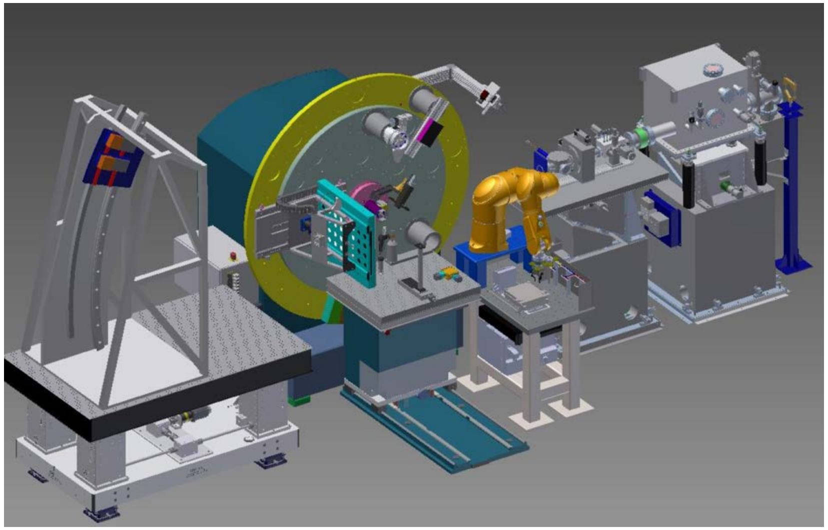
BNL Nuclear Class 1E Battery Testing Laboratory



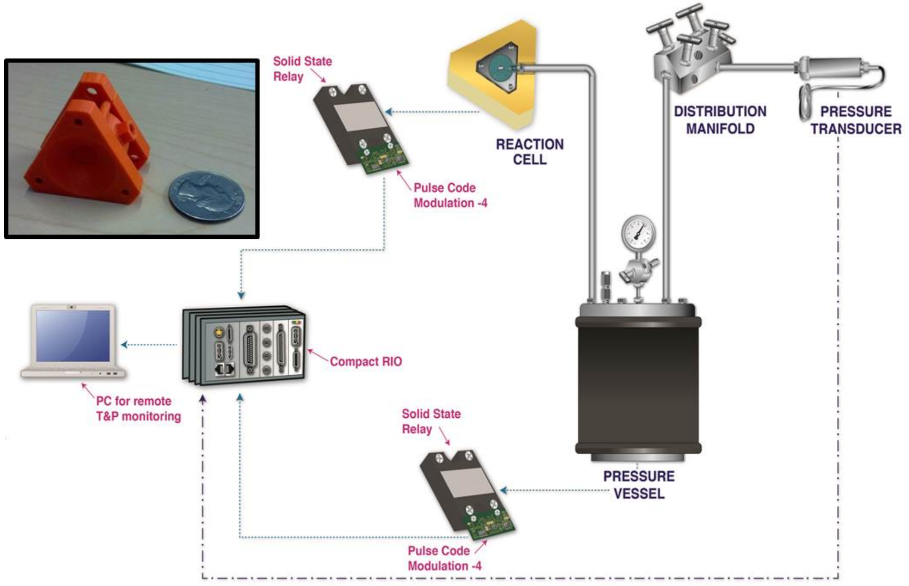
MRE is a User-Driven Facility with Strong Supporting Infrastructure

- Separate facility for materials handling and security
- Suite of containments, environmental cells, mechanical test equipment and temperature control provided
- Enable user-designed experiments
- Provide support for data analysis
- NSLS-II administrative and facility support

Infrastructure under development at BNL:



Robot for high-throughput measurements of activated samples (NEET Award FY2014)

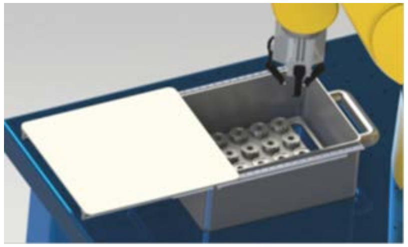


Environmental cell for in situ XRD and XRF studies of interfaces under extreme environments.

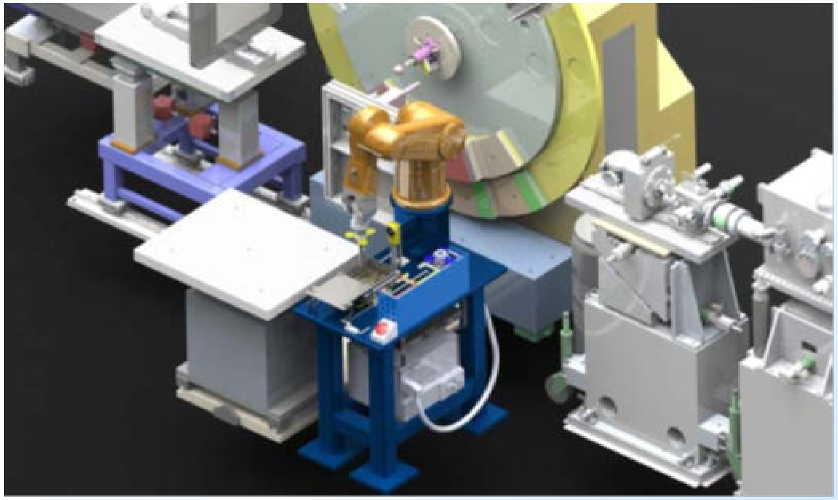
Automated Synchrotron Studies of Irradiated Reactor Pressure Vessel Steels

Experimental Plan:
Leverage large databases of irradiated materials that currently exist at facilities, such as test reactors, to better understand phases that develop late in the life of reactors.

Custom Development:
- Sample holder that can provide triple containment
- Custom sample magazine
- End arm effector or gripper for the robot



Gripper retrieving samples from a shielded magazine.



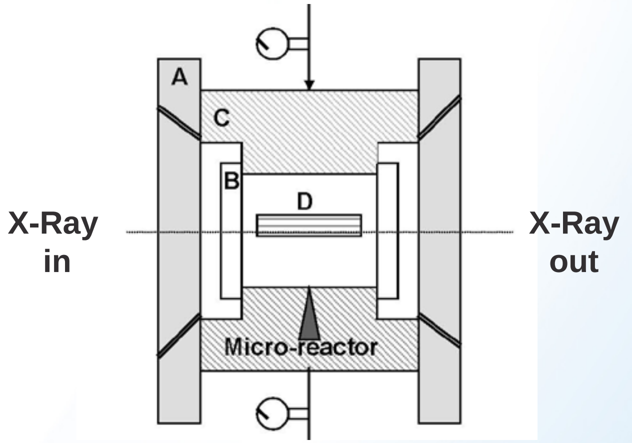
Overview of the experimental set-up showing the robot facing the diffractometer in hutch C of XPD. The experiment will be using a Perkin-Elmer flat panel detector, also visible in Figure 4 at a downstream location.

In situ Studies of Corrosion in Nuclear Fuel Cladding Materials Under Extreme Environments

Team: Simerjeet K. Gill, Lynne Ecker, George Greene, Eric Dooryhee and Michael Todosow (BNL) and Arthur Motta, from Penn State University

- Accelerated corrosion of fuel cladding materials with steam under Loss-of-Coolant-Accidents (LOCA) conditions is not well understood
- Understanding corrosion of fuel cladding materials with protective oxides that can withstand longer exposures in the reactor is crucial for safer nuclear power and achieving higher burnup in today reactors
- New capability under development for in-situ diffraction and fluorescence studies of high T accelerated corrosion
- Complementary scale-up autoclave studies for longer term bulk materials performance with wider temperature range (Ex-situ studies of thicker oxide layers)

Materials: Zirconium alloys (current), Ferritic-martensitic stainless steel or nickel-based alloy clad fuel rods. Nanostructured coatings and other new materials that show potential to survive LOCA conditions



Micro-reactor for in-situ studies*

**J. Diefenbacher, M.McKelvy, A. V.G. Chizmeshya, and G.H. Wolf, Review of Scientific Instruments, 76, 015103 (2005).*

- Goals
  - Study of oxide microstructures formed to explain differences in corrosion rates of different alloys
  - Gaining insight of underlying mechanisms and kinetics of nuclear materials under LOCA conditions
- Potential impact
  - Better predicting the failure of cladding under LOCA conditions.
  - Engineer new corrosion resistant alloys and design better cladding materials for LOCA conditions

MRE Concept and Mission

Concept: Separate facility located outside of the NSLS II ring with two endstations:

- Active materials
- Ion Beam Accelerators for in situ study of radiation damage

Mission:

- Provide a large community of users in nuclear energy and security applications significantly greater access to synchrotron characterization tools than currently exists in the US.
- Perform in situ investigations of radiation effects using ion beams (capability unique in the world)

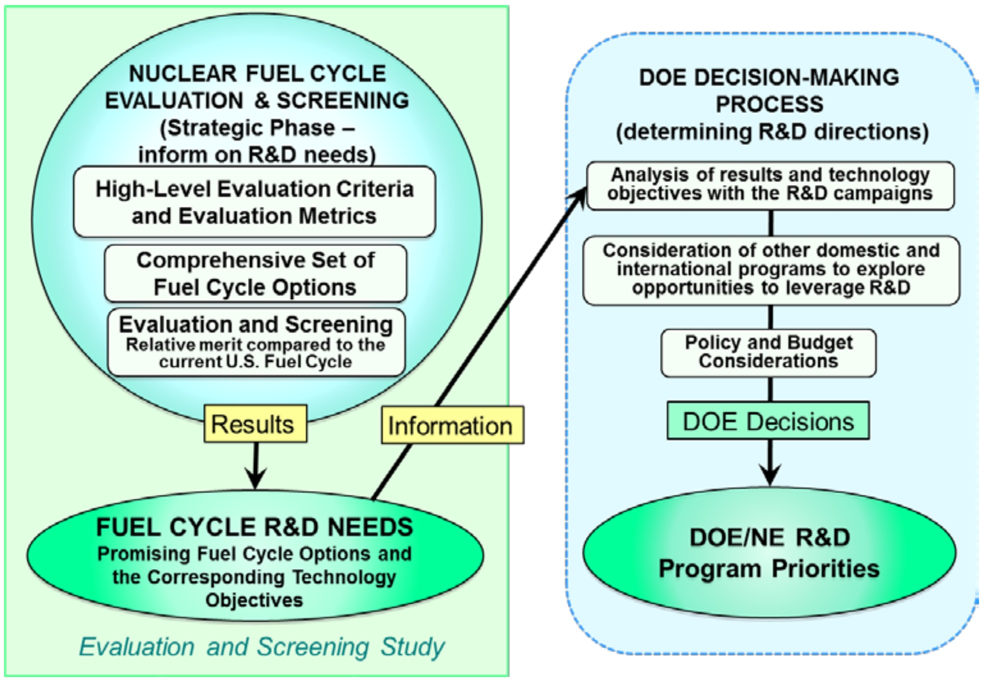
Applications:

- New materials for fission and fusion reactors such as nuclear fuels and structural materials for high radiation environments and nuclear waste forms
- Provide data for use with computer simulations, assessing material performance during off-nominal conditions, and licensing
- Nuclear forensics, security and nonproliferation applications

Impact: DOE, NRC, universities and commercial nuclear industry

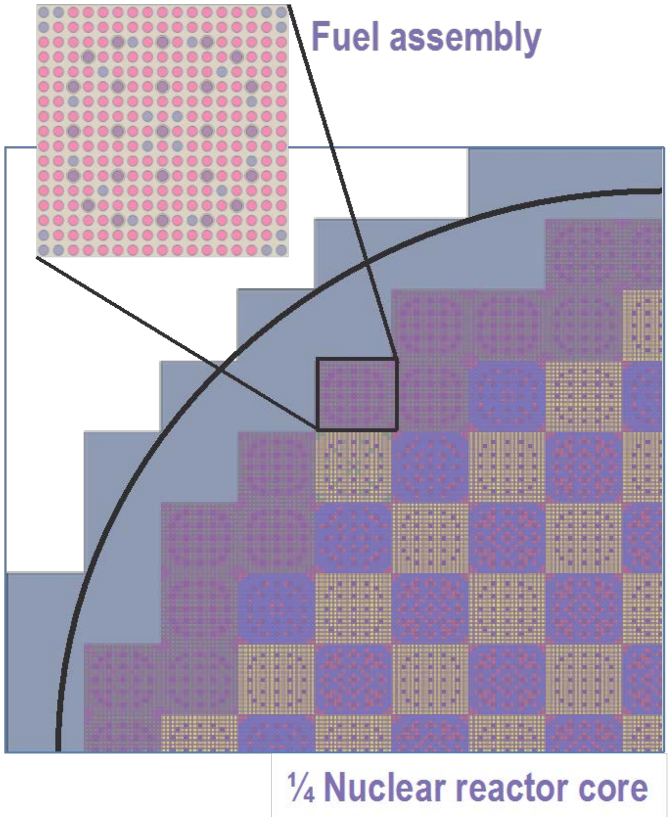
Evaluation & Screening (E&S) of Fuel Cycle Options

- Chartered by DOE-NE Office of Fuel Cycle Technologies to inform R&D planning
- Two senior BNL staff members were on the 11-person Evaluation & Screening Team which included representatives from 5 national labs and industry with expertise in all major areas
- Nine high-level criteria were specified by DOE in the Charter authorizing the work: nuclear waste management; proliferation risk; nuclear material security risk; safety; environmental impact; resource utilization; development & deployment risk; institutional issues; financial risk and economics
- Detailed fuel cycle analyses were performed at ANL, BNL, INL, LLNL and ORNL to support the development of metrics
- The objective specified in the Charter was to identify fuel cycles that would provide “significant benefits” relative to the current fuel cycle
- Since this is subjective, the results of the E&S are presented as a conditional: “if x-level of improvement is considered to be substantial, then the promising fuel cycles are…”
- Study has been completed and is being reviewed



Assessment of Performance of Fuels with Enhanced Accident Tolerance

- A scoping approach has been developed and benchmarked to evaluate the performance and safety impacts of “advanced fuels”, e.g., high burnup, inert matrix, FCM fuels
- For PWRs, assembly-level calculations generally adequate for many aspects; results were compared to reference UOX/Zr fuel:
  - Burnup/cycle length
  - Reactivity coefficients and control worths
  - Limited “systems-level” for “bounding transients” (RELAP/TRACE)
- Caution – some results can be misleading, e.g., higher thermal conductivity → smaller Doppler; lower control rod worth → smaller reactivity insertion with REA
- More detailed analyses than assembly-based are needed when performance under transient/accident conditions is the focus: three-dimensional core analyses (PARCS); PARCS-TRACE coupled transient/accident
- Recent focus on support to LANL on nitride, nitride-silicide, and fuels with UB_x
- Sensitivity studies suggested by Westinghouse



Advanced Materials Group

Challenge: Improved material performance under extreme conditions is crucial to every energy technology

Goal: Develop new, cross-cutting materials and characterization techniques that, combined with existing BNL facilities for materials testing and modeling, will shorten the time from discovery-to-deployment of a wide range of materials for advanced energy systems.

Priority Research Directions:

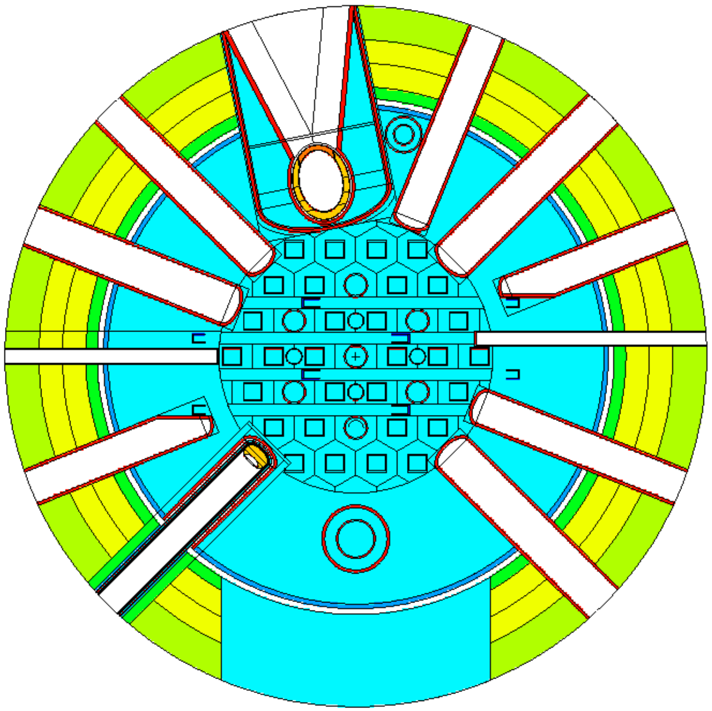
- Advanced Nuclear Energy Systems
- Geological Energy Systems

National Nuclear Data Center

- Compilation and key-wording of nuclear science publications
- Compilation of nuclear reaction data
- Evaluation of nuclear structure and decay data
- Evaluation of nuclear reaction data including covariances
- Theoretical modeling of nuclear reactions
- Formatting and verification of nuclear data files
- Development of software for dissemination of nuclear data
- Deployment and maintenance of relational databases
- Maintaining Web and database servers and collaboration software

Support for Research Reactor Analysis

- NIST research reactor (NBSR) neutronics and thermal-hydraulics
  - License renewal safety analysis report
  - Conversion from HEU to LEU



- Review of all university research reactor conversions for NRC