Capabilities at Brookhaven National Laboratory for the Advanced Reactor Demonstration Program (ARDP)

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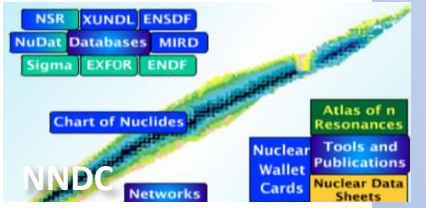
Nuclear Science and Technology Department

BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

Brookhaven capabilities that support Advanced Reactor Demonstration Program (ARDP) goals



BNL/DOE Facilities

Relevant Capabilities

- Radioactive materials characterization
- Reactor simulations
- Control room design/human factors
- Reactor licensing
- International commercialization

Partners/Joint Appointments

University *National Lab* *Industry*

Stony Brook University

INL Idaho National Laboratory

NIST

NASA

GE

UMASS LOWELL

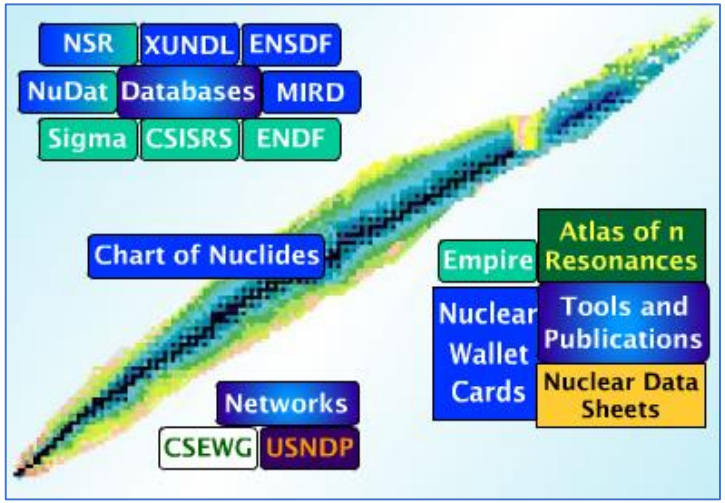
NSUF Nuclear Science User Facilities

U.S.NRC United States Nuclear Regulatory Commission Protecting People and the Environment

Westinghouse

Oak Ridge National Laboratory
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

National Nuclear Data Center



Nuclear Science References (NSR)
All nuclear physics articles indexed according to content

EXFOR
Compiled nuclear reaction data

XUNDL
Compiled nuclear structure and decay data

ENSDF
Recommended nuclear structure and decay data

ENDF
Recommended particle transport and decay data, with a strong emphasis on neutron-induced reaction data

Nuclear Data Sheets
Journal devoted to the publication of nuclear data articles

Web dissemination
www.nndc.bnl.gov

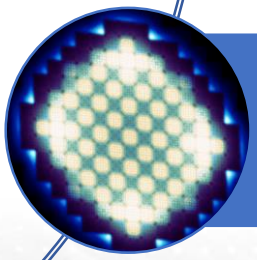
National Nuclear Data Center provides evaluated data for nuclear reactor simulations

- Contact NNDC for help
- National Nuclear Data Week in November at BNL
- Covariance for all reactions
- Assistance with covariance for specific benchmarks
- Fission yields and data evaluations

Brookhaven capabilities that support Advanced Reactor Demonstration Program (ARDP) goals

Advancing Reactor Designs toward Demonstration

Risk Reduction for Future Demonstration Reactors



Advanced Reactor Demonstrations

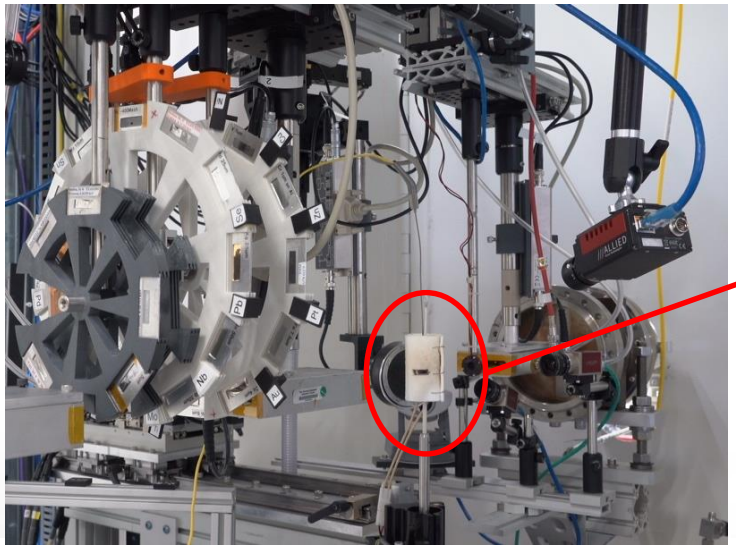
The Molten Salt in Extreme Environments (MSEE) Energy Frontier Research Center is a resource for industry

MSEE Mission: To provide fundamental and predictive understanding, based in atomistic/molecular level descriptions, of molten salt bulk and interfacial chemistry, including the effects of solutes, impurities and radiation.

Development of new MSR concepts requires fundamental understanding of, and development of predictive models for:

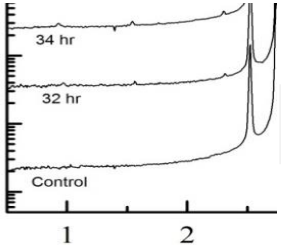
- the physics and chemistry of molten salts
- interactions with solutes (actinides, fission products, corrosion products) and radiation
- their interactions with, and degradation of, reactor materials.

The experimental techniques developed can be applied to real reactor systems – engineering alloys and salts



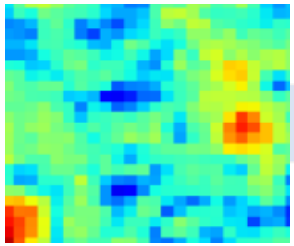
Custom made in situ furnace for molten salt studies (25ºC to 700ºC)

National Synchrotron Light Source II provides advanced characterization of materials for extreme environments



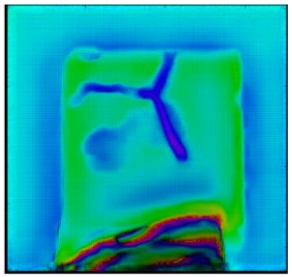
Diffraction

- Crystal structure/lattice parameters
- Strain (isotropic/anisotropic)
- Grain or domain size
- Point defects and dislocations



Spectroscopy

- EXAFS: Nearest neighbors/coordination
- XANES: Oxidation state, chemical structure
- XRF: Elemental mapping and distribution



Imaging

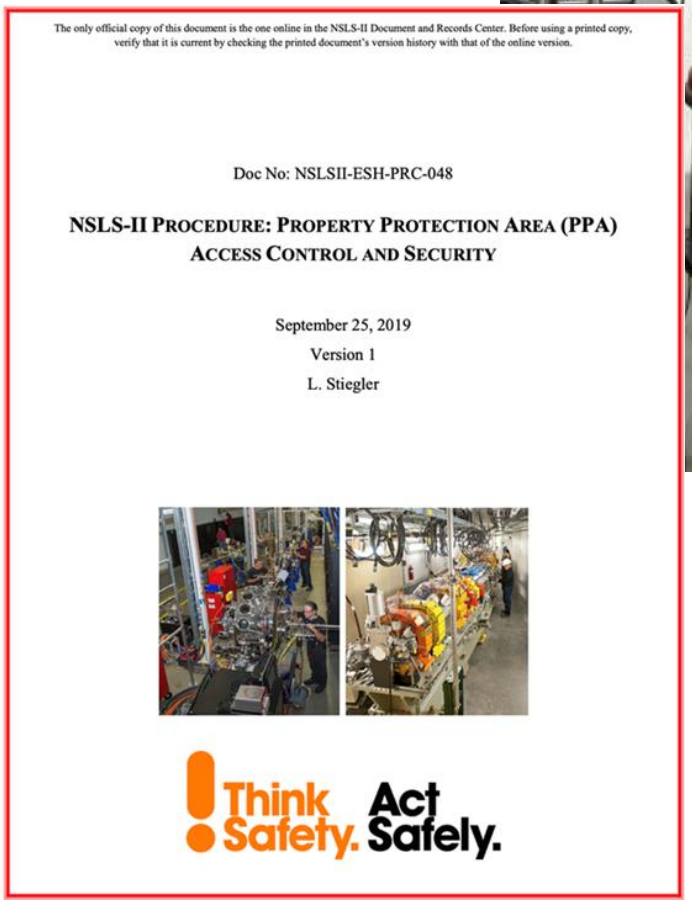
- Multiple modes of tomography
- Mapping phase and residual stress
- 2 and 3D chemical mapping

In situ Capabilities

- Real-time mesoscale microstructural development in extreme environments
- Material evolution as function of temperature, applied current/voltage and time

High throughput capabilities enable fast, unmanned sample manipulation of radioactive samples

- Special Nuclear Materials
- Robot allows hundreds of measurements in a day
- High throughput for better statistics
- Unmanned operation of radioactive samples
- Access through NSUF



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NSLS-II PROCEDURE: PROPERTY PROTECTION AREA (PPA) ACCESS CONTROL AND SECURITY

September 25, 2019

Version 1

L. Stiegler

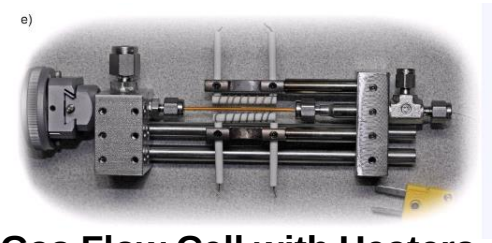
Think Safety. Act Safely.

Robot at the X-ray Powder Diffraction Beamline (XPD), NSLS-II

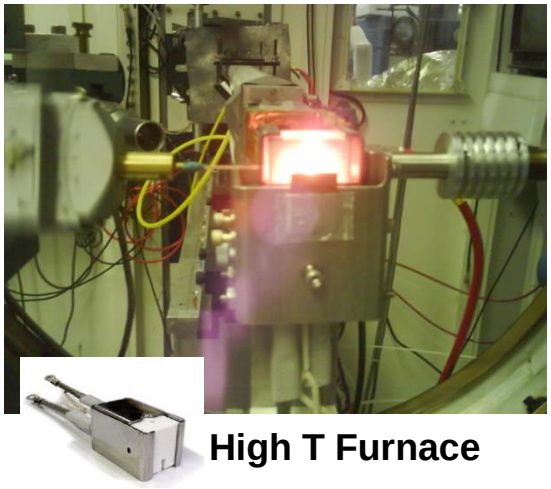
Suite of *in situ* sample environments are available for real time studies of materials under extreme environments

Capabilities:

- Temperature Range: 4K -1200˚C
- Sample Holder Type: Capillary, Flat Plate
- Gas Flow, Gas/Liquid Pressure, steam

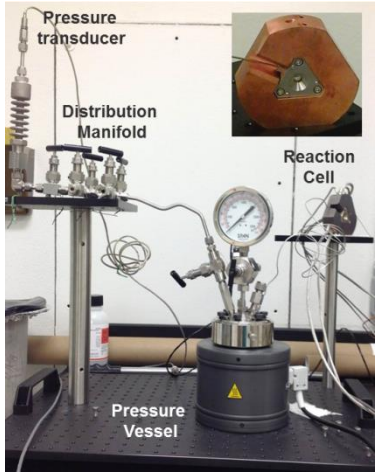


Gas Flow Cell with Heaters



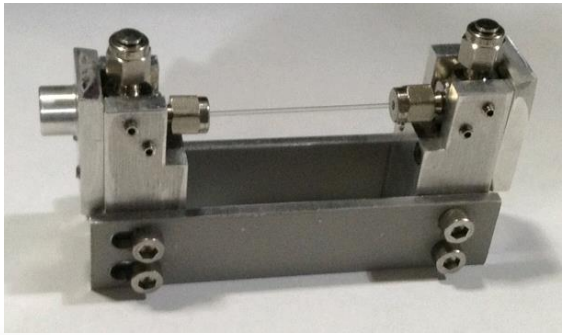
High T Furnace

Mechanical Stage



***In situ* Cell with Steam Environment**

He-Cryostat



Hydrothermal Cell

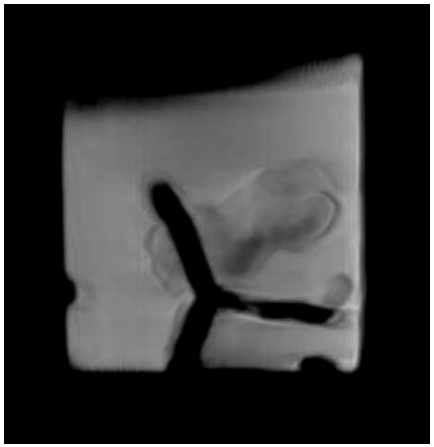
Multi-modal capabilities enable nanoscale monitoring of structural and compositional changes simultaneously to assess material performance in extreme environments

Challenge:

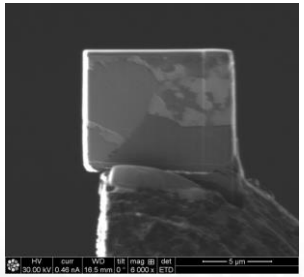
Stress Corrosion Cracking

Technique:

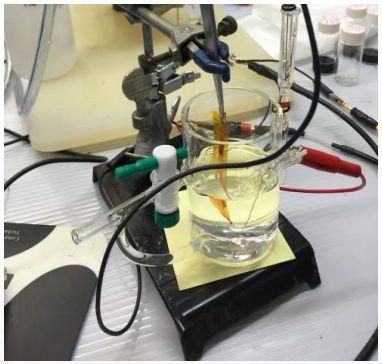
3D tomography and spectroscopy allow nanoscale monitoring cracking and mapping segregation of alloying elements at grain boundaries in single measurement



Crack Morphology from Fe Fluorescence

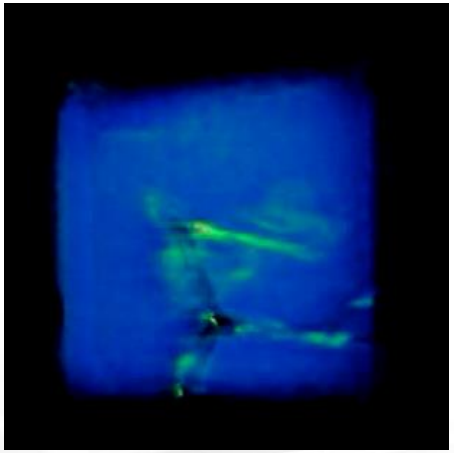


10 x 10 x 2 micron sample



Ex situ Etch

Cr Enrichment in Green (Cr/Fe ratio)

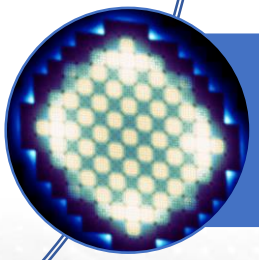


New Capability: Microdiffraction (25 x 25 micron beam) at High Energy (67 keV)

Brookhaven capabilities that support Advanced Reactor Demonstration Program (ARDP) goals

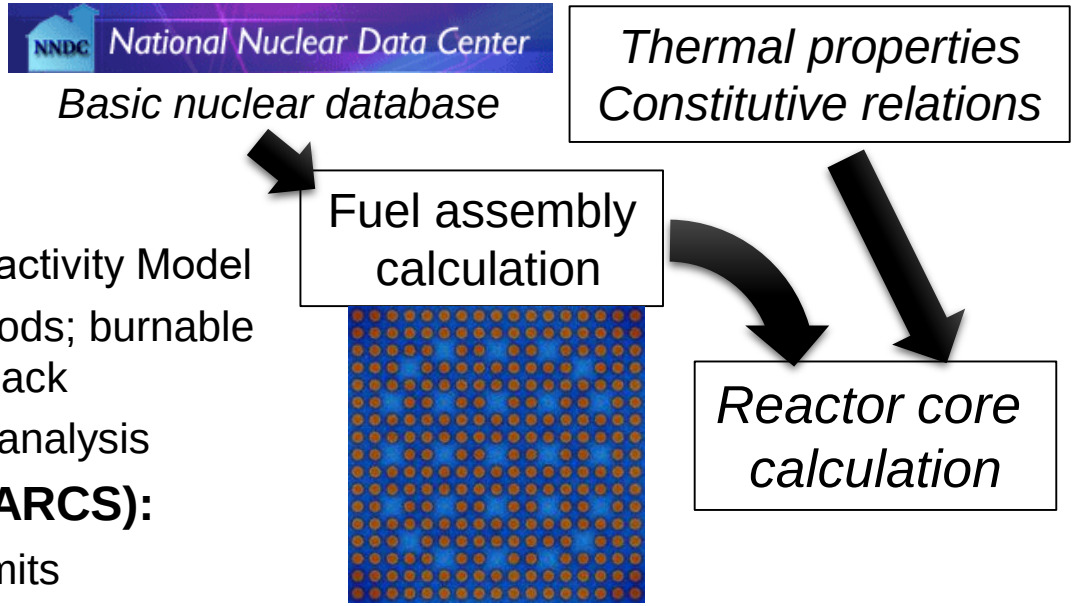
Advancing Reactor Designs toward Demonstration

Risk Reduction for Future Demonstration Reactors

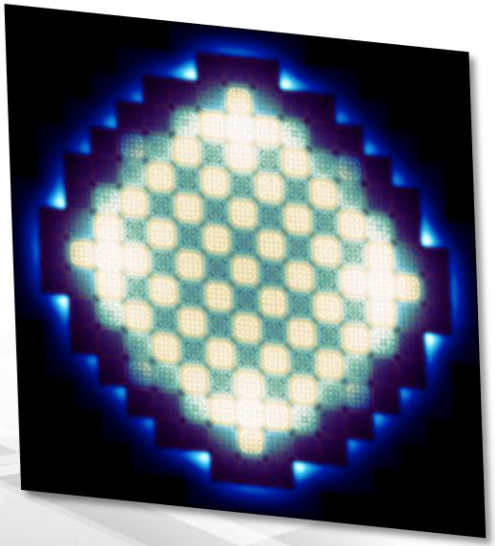


Advanced Reactor Demonstrations

BNL can simulate the reactor performance and safety characteristics of advanced designs using NRC-developed computer codes



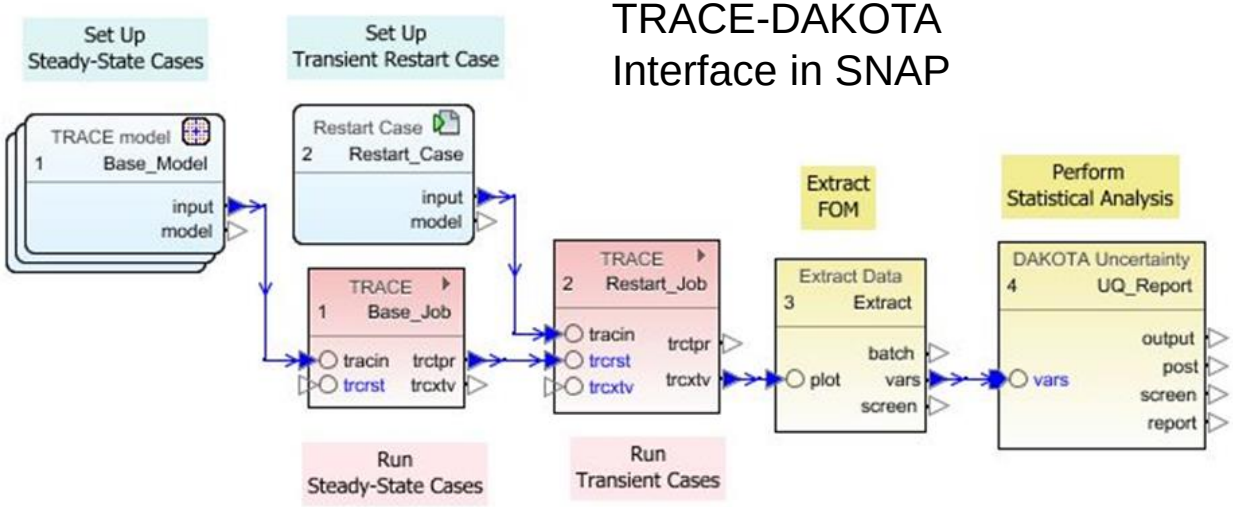
- **Assembly Analyses (TRITON):**
  - k_{eff} vs. burnup/EFPD → Linear Reactivity Model
  - Reactivity: soluble boron; control rods; burnable poisons; fuel and moderator feedback
  - Cross-section generation for core analysis
- **3-Dimensional Core Analyses (PARCS):**
  - Power distributions and thermal limits
  - Burnup distributions
  - Reactivity control (boron letdown, rod worth)
  - Core coefficients for point kinetics models
- **Transient/Safety Analyses (TRACE):**
  - Reactor systems analyses for selected transients/accidents (e.g., RIA, LOCA)
- **Additional Analysis Tools (MCNP, Serpent, VERA)**



Uncertainty/sensitivity analysis of advanced fuel concepts can be used to optimize reactor designs

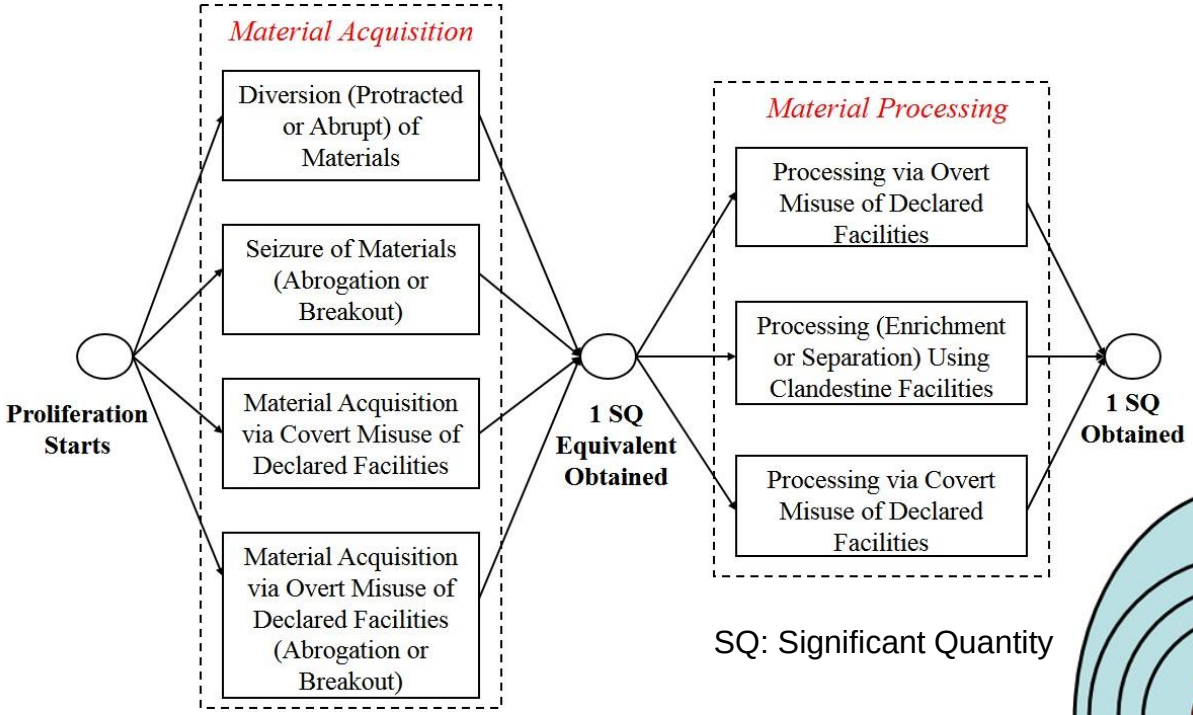
- Conduct uncertainty quantification (UQ) and sensitivity analysis (SA) for accident tolerant fuel (ATF) concepts under accident conditions using TRACE and DAKOTA.
- Generate parametric cases by random sampling of sensitivity parameters.
- Calculate figure-of-merit (FOM) for each parametric case using TRACE.
- Quantify the 95/95 one-sided tolerance limit for the FOM.
- Compute the response correlations for the FOM.

TRACE-DAKOTA Interface in SNAP



Result of UQ/SA provides indication of how different fuel parameters impact performance and thus informs areas of research to improve steady-state and accident performance.

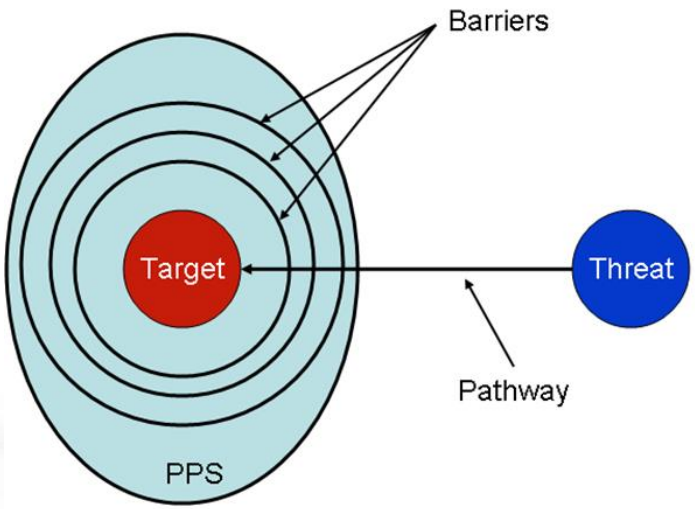
Proliferation resistance and physical protection (PRPP) of nuclear systems must be considered for international deployment



SQ: Significant Quantity

Consider both barriers:

- intrinsic (design features)
- extrinsic (safeguards/security)



GIF PRPP Evaluation Methodology:

- Target identification
- Pathway analysis
- Risk evaluation

PPS: Physical Protection System

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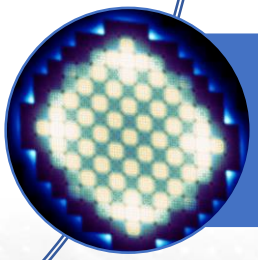
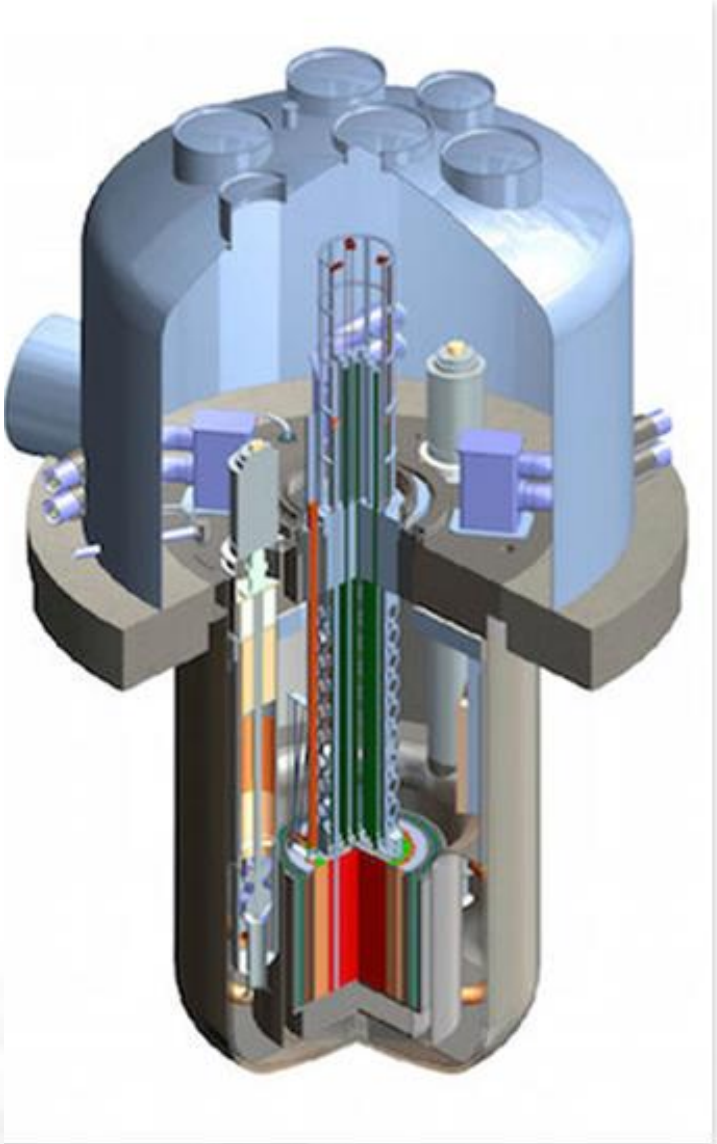


Advanced Reactor Demonstrations

Supporting advanced reactor licensing from the NRC

- Technical consultant to the NRC on safety and licensing issues for power, research, test, and special purpose reactors.
- Reviews of licensee submittals (e.g., design certification, topical reports, life extension).
- Lead on many Phenomena Identification and Ranking Tables (PIRTs).
- Support for NRC PRA Level 2 & 3 studies, nuclear power plant accident consequence analysis and emergency preparedness.
- Review of industry standard for safety-related composite modular and steel structures.



Advanced control room design includes human factors and habitability studies

- Human-systems integration
- Guidelines for control room design
- Safety reviews of new plant designs
- Control room modernization
- Human performance and reliability
- Control room habitability studies using a tracer gases
- Digital instrumentation and control
- Cyber attacks against plant protection and control

International commercialization requires international nuclear safety programs

- Improving level of safety/regulatory capabilities in countries with emerging nuclear industries/plants (Poland, Thailand…)
- Implementing agencies
  - Regulatory support by NRC/OIP
  - Additional efforts - DOS, USAID, DOE
- BNL - technical oversight, training
  - Reactor Licensing
  - Reactor Oversight
  - Infrastructure and Analytical Capability
  - Regulation and Guidance Development

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Licensing of Advanced Reactors

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Materials for Nuclear Reactors

Paul Kalb
Habitability Studies of Control Rooms

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International Regulation and Training

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Human Factors

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Reactor Simulation and Design