Introduction to Pacific Northwest National Laboratory

Pacific Northwest
NATIONAL LABORATORY
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DAVID ASNER, PhD
LABORATORY RESEARCH MANAGER, HIGH ENERGY PHYSICS

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Pacific Northwest National Laboratory (PNNL) has a strong regional and national presence

PNNL is one of the largest multi-program DOE Office of Science Laboratories

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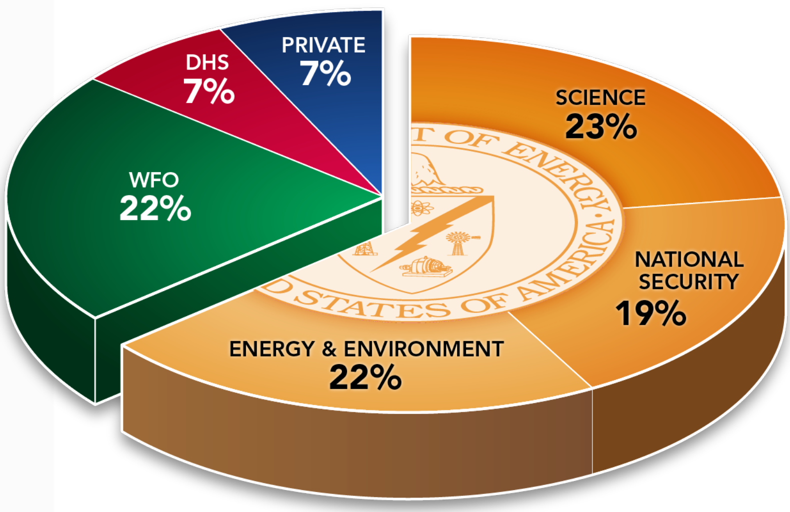
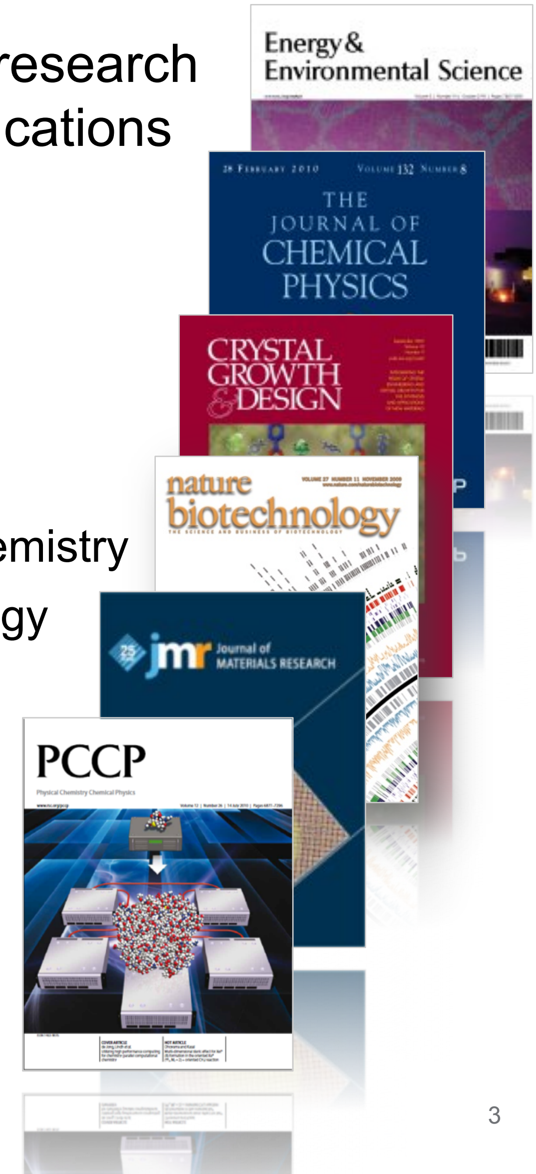
2013 Facts

- *More than 4,300 staff*
- *2000+ users & visiting scientists*
- *~$1B expenditures*



FTEs

- Among top 1% of research institutions in publications and citations in:
  - Chemistry
  - Geosciences
  - Physics
  - Engineering
  - Biology and biochemistry
  - Environment/ecology
  - Materials science
  - Clinical medicine
  - Microbiology
  - Molecular biology and genetics



PNNLs Fundamental Science Research Areas

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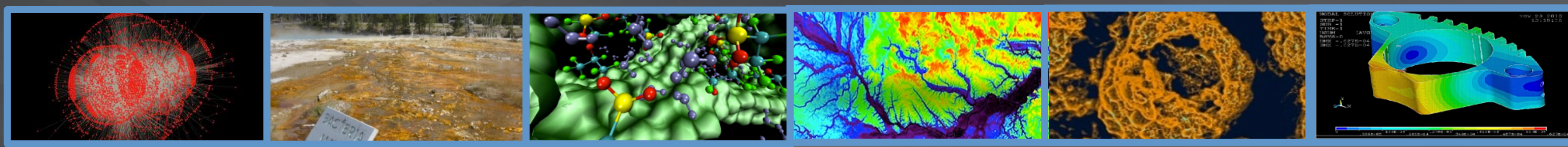

- Advanced Computing
- Biological Systems Science
- Chemistry and Geochemistry
- Climate and Earth Systems Science
- Materials Science
- Nuclear and Particle Physics

PNNL leads the U.S. Belle II Project
(the U.S. contribution to the Japanese SuperKEKB project)

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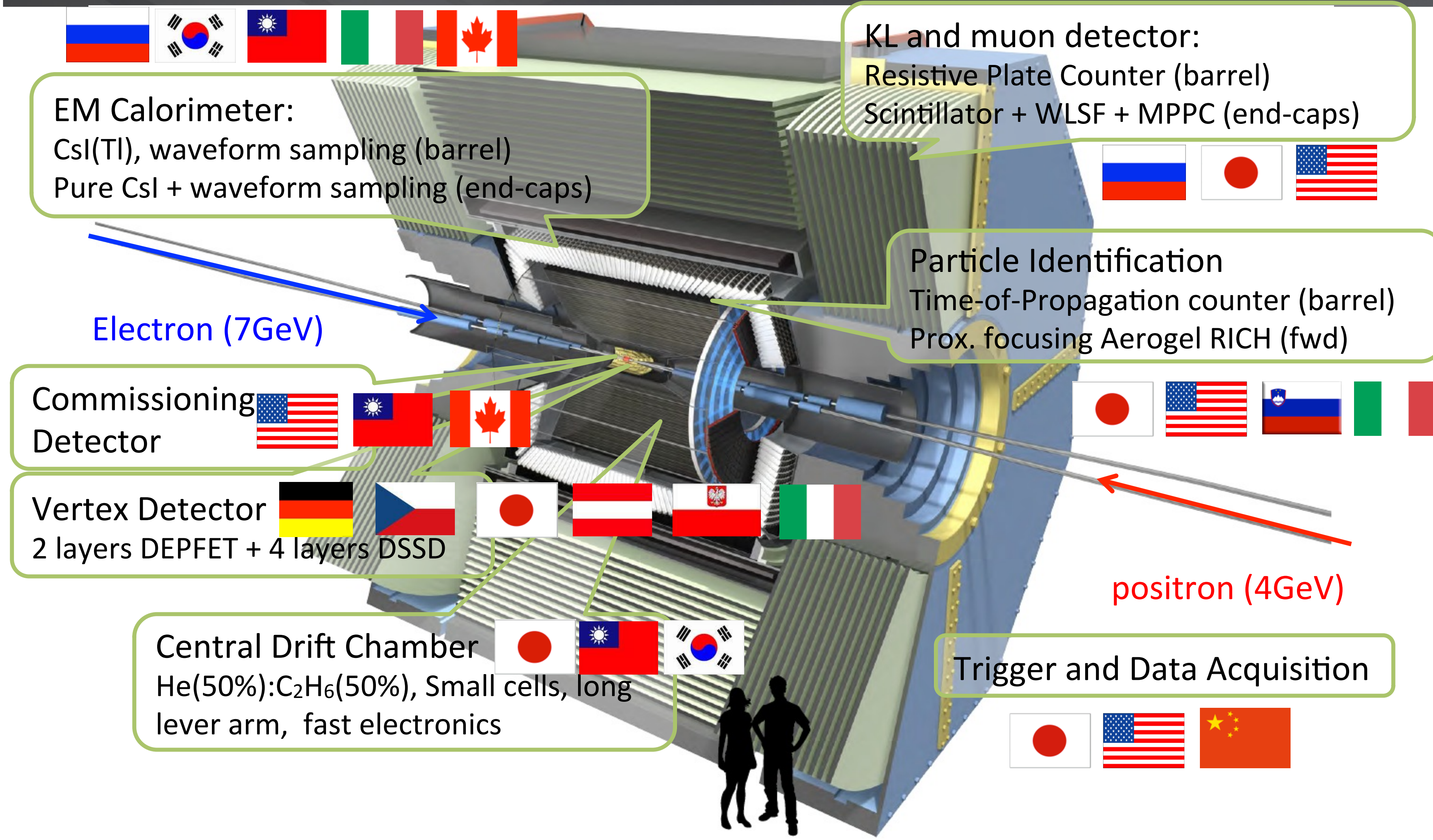
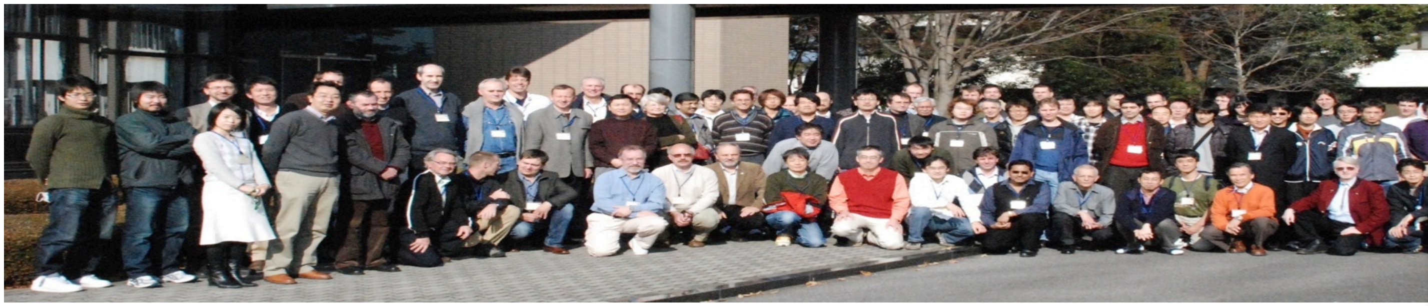


Belle II is a global collaboration



599 Members
97 Institutes
23 countries

Globally Distributed

<u>US Belle II</u>

PNNL
Carnegie Mellon
Cincinnati
Florida
Hawaii
Indiana
Kennesaw
Luther
Mississippi
Pittsburgh
South Alabama
South Carolina
Virginia Tech
Wayne State

PNNL has a broad suite of capabilities relevant to achieve the goals of the neutrino program

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- PNNL staff have designed, fabricated and operated complex target test trains in challenging high power nuclear environments demonstrating a thorough understanding of the key science questions and solutions to the difficult problems that have to be addressed to realize the neutrino physics program
- Fission reactor applications have produced candidate target materials for high power accelerators such as nuclear grade graphite, Be-base alloys, Ti-base alloys.
- New complex target designs are needed to realize the scientific goals of the international accelerator based neutrino physics
- Physics performance of targets must be optimized against both physical and material constraints.
- PNNL experience in the design of irradiation targets inserted in reactors requires the same analysis, prototyping and fabrication tools as accelerator target/window design
  - Subject to the formal quality standards of the nuclear power industry
  - Severe consequences to target failure in a reactor

PNNL Capability

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- Material Sciences (Irradiated material characterization & testing)
- Remote Handling and Hot Cells for Post Irradiation Examination (PIE)
- Design Analysis and Simulation (Target/window development & design)
- Precision Component Development and Fabrication
- Instrumentation and Control
- Accelerator Test Enclosure Design and Documented Safety Analysis

PNNL Irradiation Laboratories (318 Bldg)

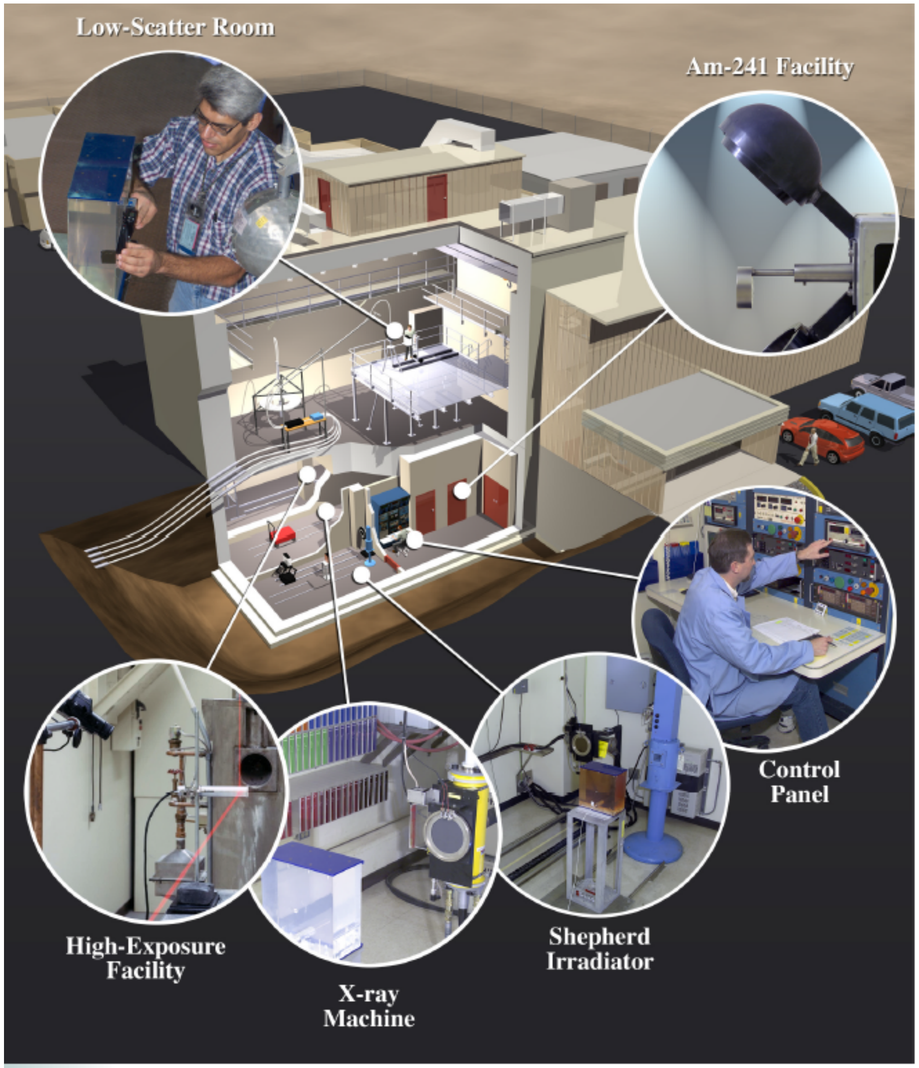

Figure 2.3 318 Building Ionizing Radiation Laboratories. The 318 building contains a wide variety of ionizing radiation laboratories and radiation generating devices, many of which are housed in the former reactor containment illustrated here.

- The upper containment area, a concrete room of dimensions 10x9x15 meters, is a low-scatter facility with 14 MeV neutron generators
- The lower containment area is partitioned into x-ray (4.7x12.6x4.0 meters) and high-gamma exposure (15.2x3.7x3.7 meters) facilities capable of delivering a large-volume, uniform gamma radiation field (up to 5×10^4 R/h) for calibrations or evaluating the effects of radiological dose on materials.
- On the ground floor, outside the low-scatter facility are the beta standards laboratory and the source well room.

PNNL Radiological Aberration-Corrected TEM

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Cold field emission gun (CFEG)

- Lower energy spread (ΔE<0.3 versus 1 eV for 2010F)
- 1000x higher brightness

Aberration correction provides sub-angstrom probes.

- Sub-angstrom atomic resolution, 85x improvement in probe current density

Tremendous improvements

- *Atomic resolution EELS, EDS, Image Acquisition*
- *Drift-free elemental mapping in minutes, not hours*
- *High contrast atomic imaging*

No other national laboratory has such an instrument for radiological materials characterization

PNNL has full suite of basic and advanced test systems to study material property degradation from radiation damage

- Changes in material properties from radiation effects in accelerator target materials and beam windows can be life limiting
  - For example, the buildup of helium from nuclear reactions can be life limiting for some materials
- PNNL scientists and engineers
  - have developed the capability to measure He in very low concentrations in steels
  - have experience in relating high fluence effects to material property degradation
  - have developed molecular dynamics methods for modeling displacement cascades at atomistic levels
  - have established dosimetry capabilities that would be useful in benchmarking actual conditions against predictive design codes
- PNNL's Radiochemical Processing Laboratory (RPL) provides the ability to routinely work on and test activated samples.

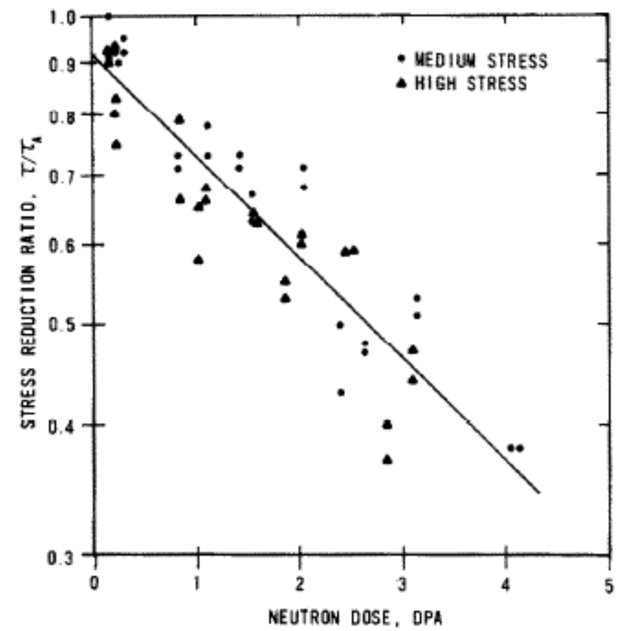

Fig. 5. Stress-reduction ratio as a function of neutron dose for the medium- and high-stressed inconel X750 springs irradiated in the SURV 1, 3, 4, and 5 subassemblies.

Radiochemical Processing Laboratory

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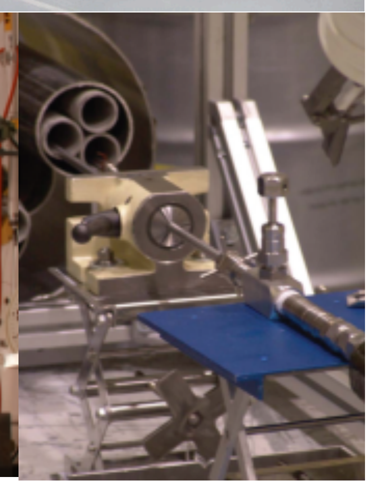
- Cornerstone of PNNL Capability Replacement Laboratory to facilitate cutting-edge science with radioactive materials using state-of-the-art equipment and instrumentation
- Laboratories and hot cells designed for work with nonradioactive materials, microgram to kilogram quantities of fissionable materials, and megacurie quantities of other radionuclides
- Extensive specialized features and instrumentation to identify and quantify chemical species and radioactive isotopes in simple and complex media
- Capability to develop automated radiochemical sensors, process monitors
- Capabilities to perform post irradiation examination of irradiation tests
  - Dosimetry services can help characterize complex irradiation environments
  - Remote cutting, handling, and disassembly methods
  - Microscopy, isotope assay, surface analysis
  - Shielded SEM can analyze highly radioactive samples

Remote Handling and Hot Cells for Post Irradiation Examination at RPL

- Radiochemical Processing Laboratory: DOE hazard category 2 facility for work with mg to kg of fissionable and non-fissionable radioactive materials
- 144,000 ft^2 building with 40,000 ft^2 of laboratory & more than 8,500 ft^2 of hot cell space (16 hot cells)
- Extensive wet laboratories, shielded glove boxes, wet radiochemistry fume hoods, and a modern analytical lab
- $40M in recent upgrades:
  - Seismic strengthening
  - 4 new hot cells
  - 3 new glove boxes
  - 2 new modular shielded storage units
  - High Level Radiation Facility C-cell cleanout and window replacement



Design Analysis and Simulation: High Power window and target development and simulation

- PNNL has extensive capabilities with proven performance of target designs in challenging complex nuclear/thermal environments.
- Core design expertise includes, molecular dynamics, and kinetic Monte Carlo modeling.
  - Radiation transport and heating is typically accomplished with MCNP6.
  - The primary thermo mechanical modeling tools include ANSYS, MathCad
  - Three dimensional component modeling is completed using SolidWorks
- PNNL designed reactor targets have performed extremely well
  - multiple Tritium Technology Program test trains installed in the Advanced Test Reactor (ATR) at Idaho National Laboratory (INL)
  - fusion materials testing in the Fast Flux Test Facility at Hanford
- Successful test performance has required evaluation of radiation damage of materials, structural design, thermal management, weld development, unique weld joint design, designs to facilitate remote handling, and post irradiation examination.

PNNL Experience: Irradiation Target Design

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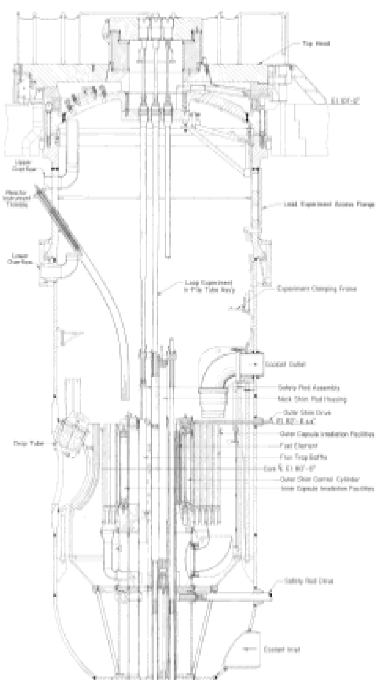
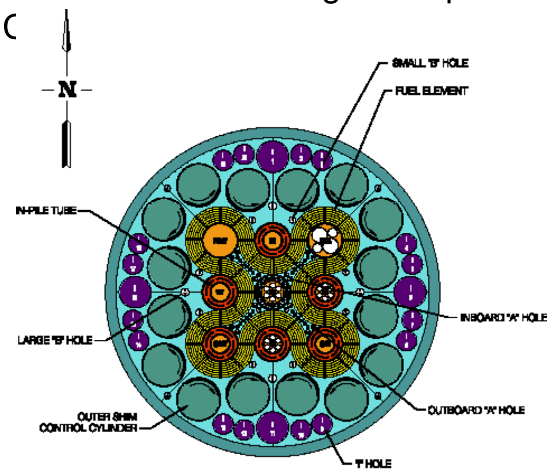
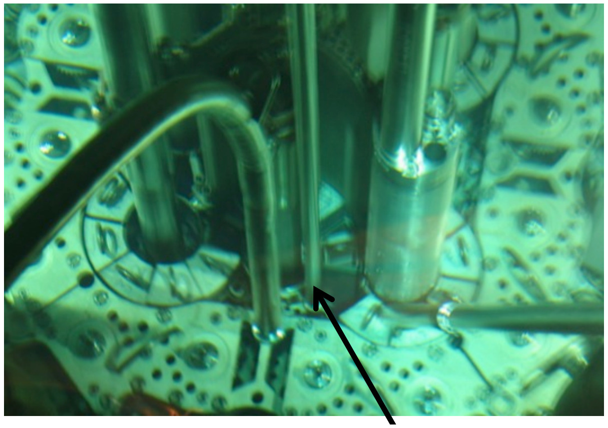
- Extensive Capabilities with Proven Performance of Target Designs in Challenging Complex Nuclear/Thermal Environments
  - Advanced Test Reactor (ATR) Irradiation Targets
    - Max thermal power = 110MWt (22 MWt per lobe)
    - Max thermal neutron flux=1E15 n/cm^2/s in flux trap
    - Water cooling/ beryllium reflection/ inert gas temperature control systems, typical test temperatures from 50°C to 1000°C





ATR CORE CROSS SECTIONAL DIAGRAM



TMIST-1 leadout in the ATR B-2 position

- PNNL Tritium Technology Program supports design, development, demonstration, testing, analysis, and post irradiation characterization of Tritium-Producing-Burnable-Absorber-Rods (TPBAR) for NNSA
- TMIST (TPBAR Materials Irradiation Separate-Effects Test) is a series of irradiation tests in ATR designed, developed, and executed by PNNL for the Tritium Technology Program
- PNNL is Design Agency for Program
- Issues: Thermal management, active temperature control, activation, tritium containment

Target Thermal and Structural Design

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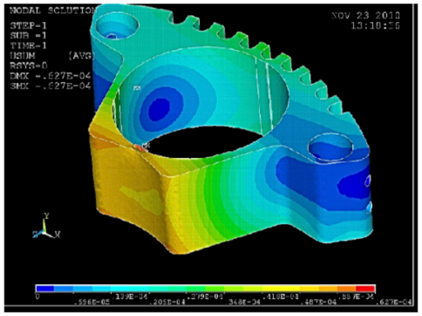
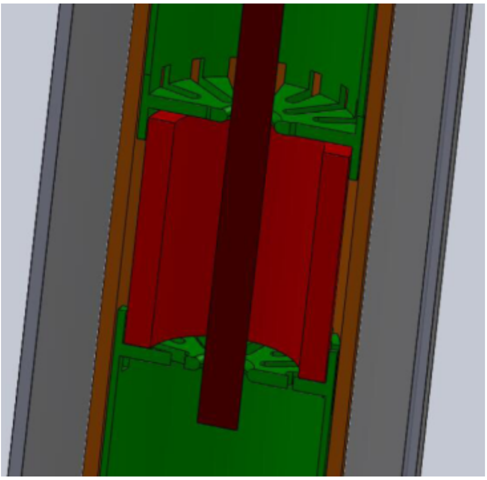
- ANSYS structural code – mechanical, thermal and multi-physics modeling capabilities to design a target that will perform under demanding and complex heat deposition conditions
  - Irradiation energy deposition
  - Conduction, convection, radiation
  - Thermal gradients
  - Gas mixtures and control
  - Solidworks 3D modeling
  - Dynamic transient analysis
  - Linear/nonlinear stress analysis
  - Modal analysis/natural frequencies
  - Incorporates irradiated material properties





- These modeling capabilities have been proven through years of successful in-reactor irradiation testing

Precision component development and fabrication

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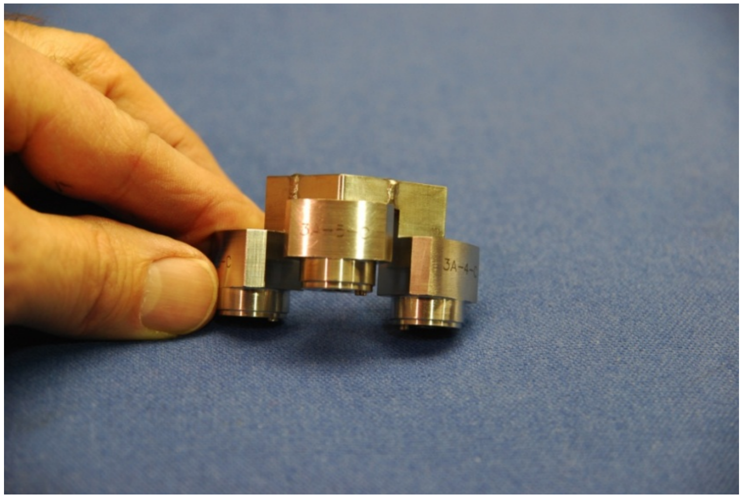
- PNNL has designed and fabricated complex machined parts for target test train use in reactors.
- Fabrication capabilities include high precision EDM & CNC machines
- Automated programmable welding using TIG, laser, & E-beam methods.
- Expertise in innovative additive manufacturing used for complex three dimensional components.
- Designed unique weld joints for nuclear applications
  - experience in welding these joints and joining ceramics such as SiC.
- Various unique approaches have been developed and used for differential strain relief under dynamic conditions.
- PNNL capabilities include weld joint and braze design, specification and qualification for E-Beam, TIG and laser welding, American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code compliance and analyses, and satisfying the commercial ASME NQA-1 Quality Assurance Programs required by US Nuclear Regulatory Commission (USNRC) for reactor applications.

Unique Development, Design, Fabrication, and Assembly of Precision Compoents

- PNNL has designed and fabricated complex machined parts for use in reactors
- PNNL has designed unique weld joints for nuclear applications and has experience in welding these joints
- In addition to welding, PNNL has experience in joining ceramics, particularly SiC, but others as well
- Various approaches used for differential strain relief



TMIST-3 Upper End Plug, illustrating unique fabrication and joining solutions for in-reactor tests

The holes shown in the end cap photo are 0.020 inches in diameter

Mini-Flex Hydroformed Bellows

Welding and Brazing

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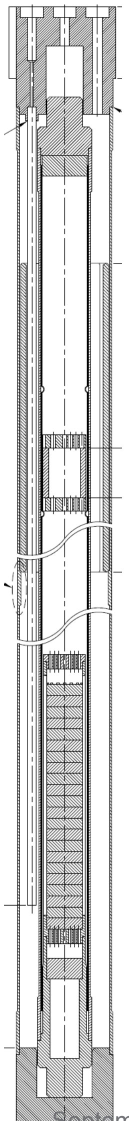
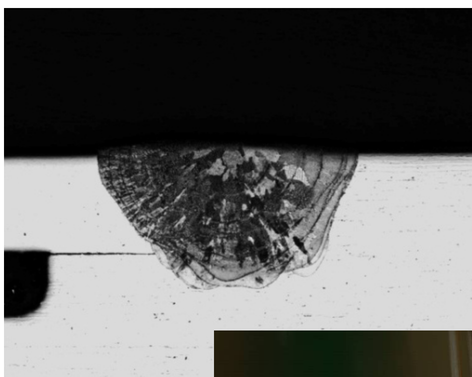
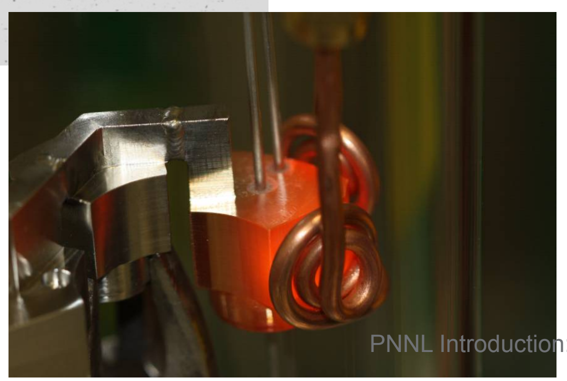
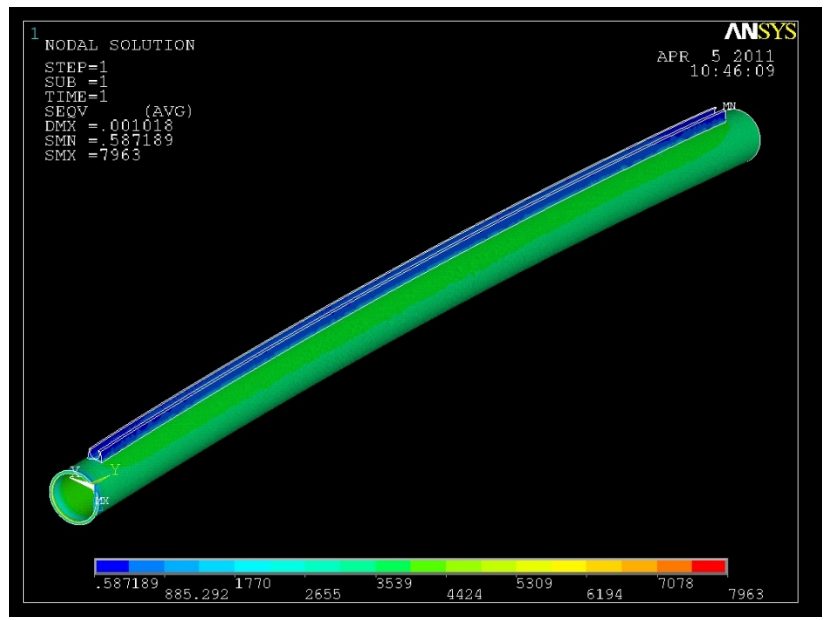


- Weld Joint and Braze Design, Specification and Qualification
- E-Beam, TIG and Laser Welding Capabilities
- American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code Compliance and Analyses
- Commercial ASME NQA-1 Quality Assurance Program required by US Nuclear Regulatory Commission (USNRC) for reactor applications



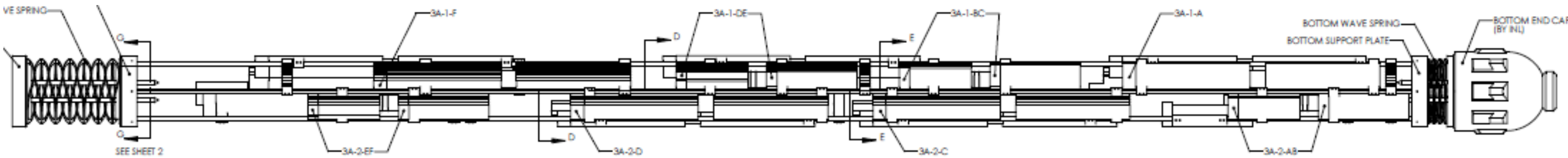
TMIST-3 Test Fabrication Analysis



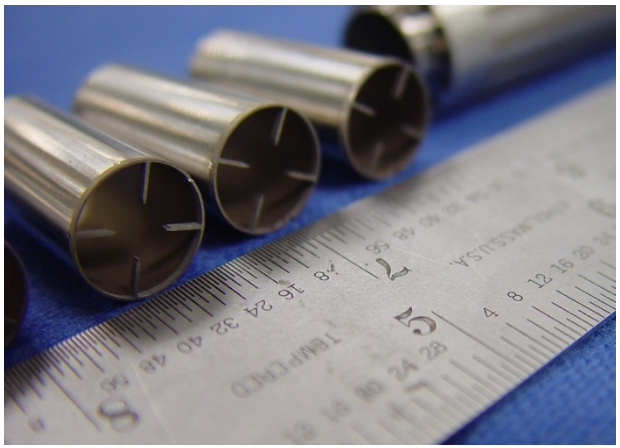


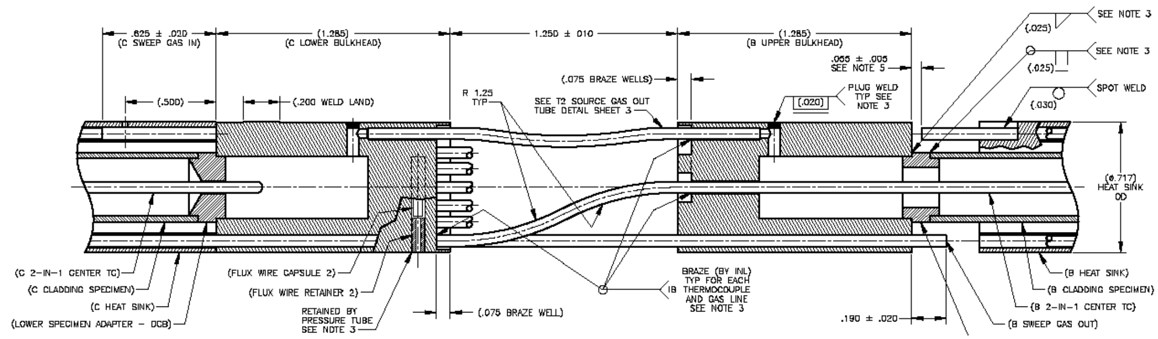
Proven Target Fabrication and Performance

In many respects, design of in-reactor targets can be more demanding than accelerator targets

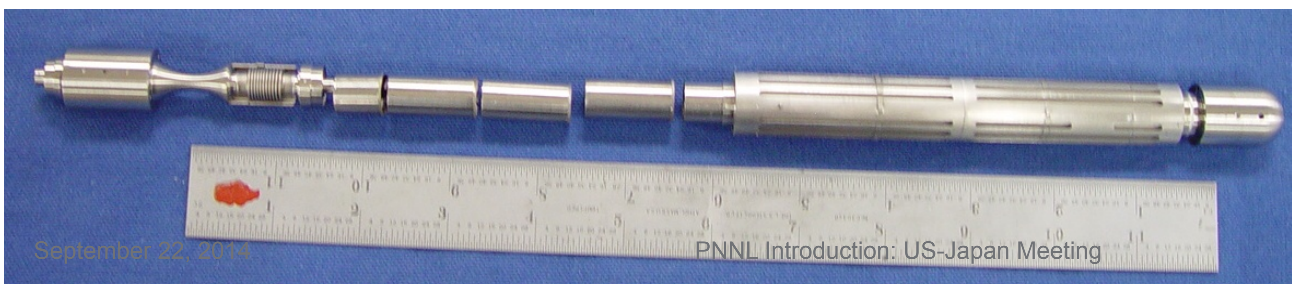


TMIST-3 In-Reactor Test Cage Assembly





TMIST-2 In-Reactor Tritium Permeation Test Assembly with Real-Time Instrumentation and Control



Development of Advanced Instrumentation and Control for Reactors → Accelerators

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- PNNL supports a program for the DOE Department of Nuclear Energy to develop advanced instrumentation, controls, and human-machine interface (ICHMI) technologies for advanced small modular reactors (AdvSMRs) that could prove applicable to new accelerators
  - Critical material degradation issues include: volumetric swelling and dimensional stability, embrittlement, stress corrosion cracking, irradiation and thermal creep, and corrosion
- PNNL is focused on enhancing risk monitoring technologies with integrated equipment condition assessment of active components and prognostic health management of passive components
  - Enhanced risk monitoring methodology integrates real-time information on equipment condition and the probability of failure into risk monitors that provide an assessment of dynamic risk as equipment ages
- In accelerators, degradation in all passive and active components will need to be well-managed to maximize safety, operational lifetimes, and facility reliability while minimizing maintenance demands.

Closing comments

- PNNL physicists and engineers are eager to contribute expertise to enable the future program of discovery in accelerator based neutrino experiments
- The reactor heritage of PNNL provides a broad suite of capabilities in material science, remote handling, design analysis and simulation, precision component development and fabrication to address the challenges of the high power accelerator environment
- PNNL has a strong relationship with Japan in HEP and beyond
  - PNNL is leading the US DOE role in Fukushima response and clean-up
  - July 2014 – Members of Japanese DIET visit PNNL
  - PNNL Director visited KEK and KEK Director General visited PNNL
  - KEK-IPNS Director Masanori Yamauchi visits to PNNL in 2011 & 2014
  - Multiple visits of PNNL management to KEK and J-PARC
  - Strong KEK/PNNL relationship on Belle (detector upgrade, computing Tier-1)
  - April 2015 – PNNL to host US-Japan Collaboration on HEP meeting

PNNL has a broad suite of capabilities relevant to achieve the goals of the neutrino program

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