



Recommended Best Practices Derived from Test Reactor Irradiation Experiments

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RaDIATE Collaboration Meeting
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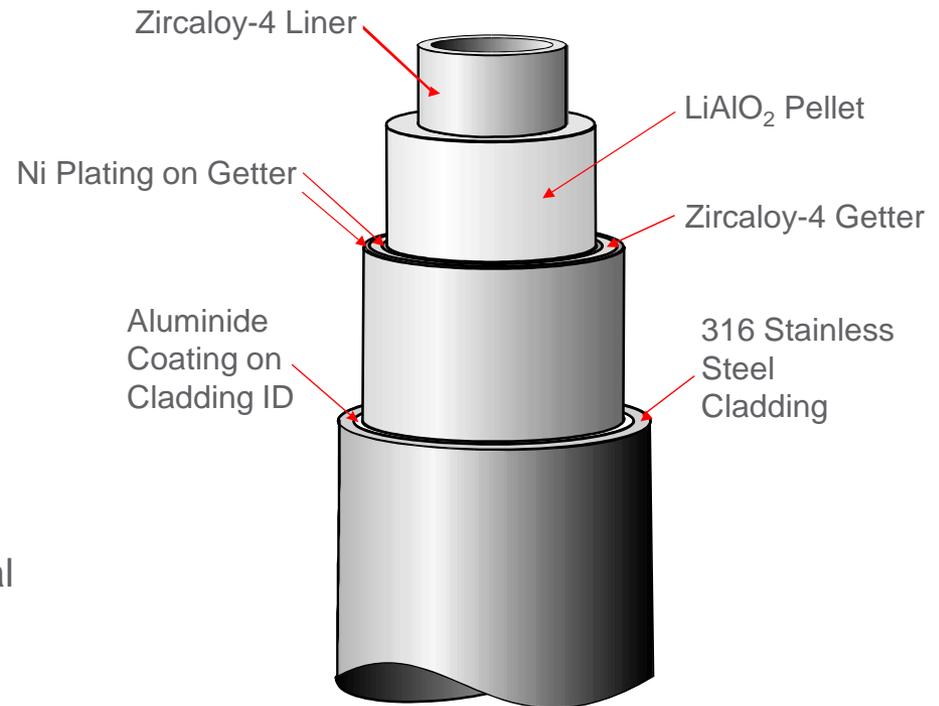


PNNL is operated by Battelle for the U.S. Department of Energy

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Background

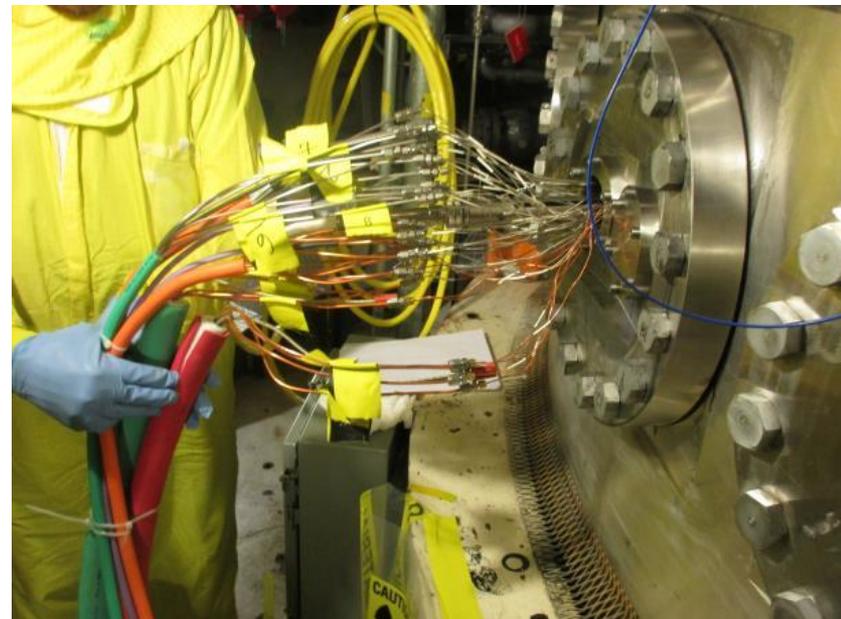
- PNNL is the design authority for tritium-producing burnable absorber rods (TPBARs) that are irradiated in a commercial nuclear power plant
 - TPBARs are categorized by the US Nuclear Regulatory Commission as Safety Related/Basic Components
 - All TPBAR design and fabrication activities must conform to quality requirements specified by US federal law for commercial nuclear power plants (10 CFR 50, Appendix B)



Not to scale

Background

- PNNL is responsible for coordinating all R&D efforts related to TPBAR materials and components, including in-reactor performance testing
 - Three large-scale experiments (TMIST-1, -2, -3) have been irradiated at the Advanced Test Reactor (ATR) at Idaho National Laboratory starting in 2006 and continuing to the present
 - All supporting data used in TPBAR design must be generated under a quality assurance program that meets the requirements listed above to ensure appropriate pedigree
 - As a US Department of Energy facility, the ATR adheres to a quality assurance program compliant with ASME NQA-1, which meets the requirements in 10 CFR 50, Appendix B

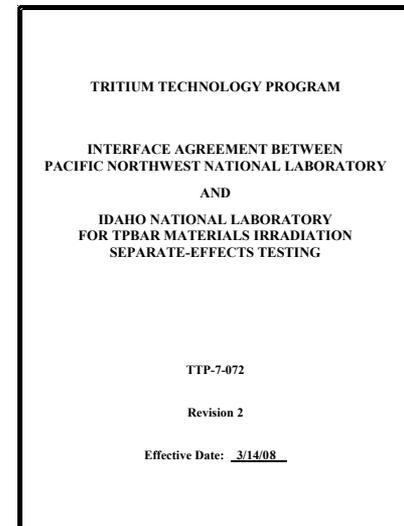
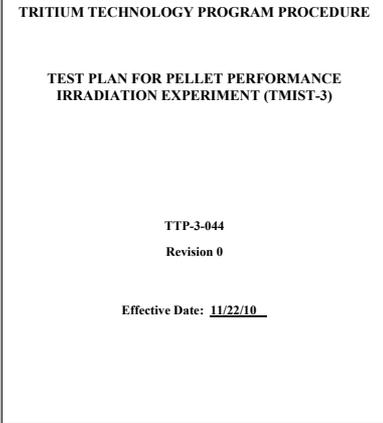


Recommended Best Practices

- It is not necessary or even desirable to employ a rigorous NQA-1 type quality program for accelerator materials irradiation experiments
- However, employing a graded approach to quality might be beneficial for future proton irradiations without adding excessive cost or burden
- The following slides provide examples of practices that the targetry community can consider for future irradiation experiments
 - Some of the details may not be relevant for proton irradiation of accelerator materials but they are provided to illustrate practices that have been useful for the TMIST experiments

Planning

- All TMIST experiments began with a test plan
 - Defines high-level test objectives
 - Defines criteria for success
 - Defines which organizations are responsible for providing samples, test hardware, design calculations, irradiation, etc.
 - Defines interfaces between organizations
 - Establishes quality assurance requirements and expectations
 - Defines required documentation to support sample/hardware traceability or technical services
 - Establishes consistent sample identification protocol to avoid confusion/duplication
 - Establishes schedule and milestones to set expectations
 - Provides a definition of scope to assist each organization with budget planning
- Test plans can be supplemented by interface agreements between participating organizations if more formal communications protocols are warranted
 - Each TMIST experiment had an interface agreement between PNNL and INL to explicitly define roles and responsibilities, controlled document procedures, communications protocols, reporting requirements, etc.



Design Reviews

- TMIST design reviews include two parallel sets of meetings
 - Technical or programmatic design reviews
 - ✓ Ensure that the programmatic objectives will be achieved by the proposed experiment design
 - ✓ Hosted by the experiment designer (e.g., PNNL for the TMIST experiments)
 - Operational or safety design reviews
 - ✓ Ensure that the proposed experiment design will operate safely in the irradiation facility
 - ✓ Hosted by the irradiation facility (e.g., ATR for the TMIST experiments)
- Design Review Board
 - Comprised of individuals that are independent of the design activity
 - ✓ A chair is appointed to invite DRB members, draft the agenda and direct proceedings
 - ✓ A secretary is appointed to record action items, coordinate review comments and resolutions, and issue formal meeting minutes
 - Membership is broad and includes relevant technical experts and representatives of all stakeholders
 - ✓ Neutronics, thermal/hydraulics, structural, materials, tritium experts (can be from design authority's organization, external organizations or a mixture)
 - ✓ Representatives of the organizations responsible for fabrication, irradiation (technical and operations), transportation, and post-irradiation examination
 - DRB members provide comments verbally during the design review, but also submit written comments following the review
 - ✓ All written comments must be resolved in writing by the designers before a deadline agreed during the review but before the next review
 - ✓ Resolutions must be approved by the originator of the comment

Design Reviews

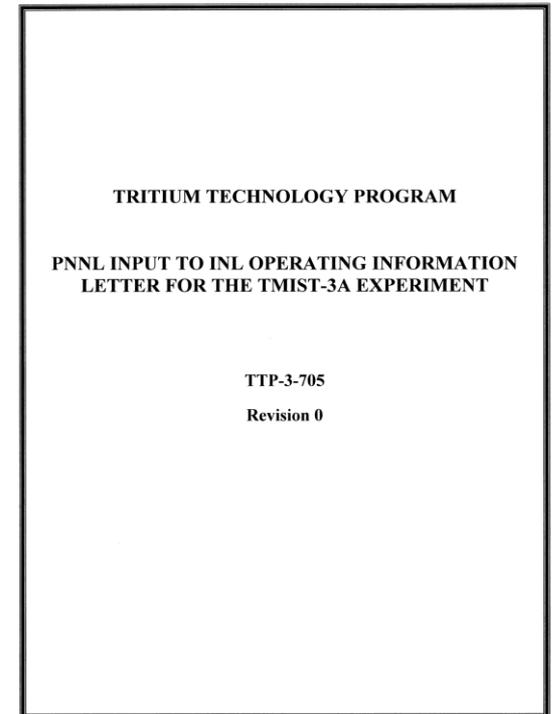
- TMIST design reviews are conducted at three stages of design maturity
 - Conceptual (design is ~10% complete)
 - ✓ Establishes technical approach for achieving experiment objectives defined in the test plan
 - ✓ Provides conceptual design for experiment hardware
 - ✓ Provides very preliminary calculations to assess likelihood of experiment success
 - ✓ Allows major course corrections without significant investment in design
 - ✓ Test matrix is frozen after the conceptual design review comments are resolved
 - Preliminary (design is $\geq 75\%$ complete)
 - ✓ Most of the investment in design happens during this phase
 - ✓ Design calculations (neutronics, thermal-hydraulics, structural) are essentially complete
 - ✓ Major hardware features are fixed by the preliminary design review
 - ✓ Design is frozen after the preliminary design review comments are resolved
 - ✓ Drawings are often released for fabrication after preliminary design review comments are resolved
 - Final (design is 100% complete)
 - ✓ Ties up any loose ends remaining from the preliminary design review
 - ✓ Clarifies any outstanding technical questions or issues
 - ✓ Provides confidence that all previous calculations and drawings are valid and complete
 - ✓ Provides an update on fabrication status and any design changes that may have resulted from fabrication activities
 - ✓ Can be eliminated if the DRB agrees all outstanding issues are resolved after addressing preliminary design review comments

Design and Fabrication Documentation

- Configuration control is very important to ensure all stakeholders are working with current versions
 - New versions of controlled documents are typically distributed to stakeholders immediately upon release
- Material specifications and/or formal drawings
 - Product requirements (materials, dimensions, tolerances, finish, etc.)
 - Fabrication process requirements
 - ✓ Product specifications are typically preferred to process specifications when possible
 - Sampling, inspection and acceptance criteria for materials or hardware components
- Assembly specification
 - Provides the sequence for assembling test hardware
 - Defines handling, environmental, transportation and cleanliness requirements
 - Defines qualification process for special processes (e.g., welding, brazing, heat treatments, coatings, etc.)
 - ✓ For example, demonstration of acceptable welds at minimum and maximum heat parameters
 - ✓ Acceptable welds defined by requirements on inspections that can include visual, dye penetrant, He leak, x-ray, ultrasound, metallography, etc.
 - Defines inspection and acceptance criteria for subassemblies and/or final assembly
 - Provides a record that each assembly step was properly completed (fabrication traveler)

Experiment Operation Documentation

- All TMIST experiments are operated by ATR with procedures derived from a document called the Operating Information Letter that includes all relevant guidance
 - Instructions for experiment operation
 - Temperature and gas flow setpoints
 - Alarm setpoints
 - Alarm actions and notifications
 - ✓ If Alarm X occurs, contact the INL experiment engineer
 - ✓ If Alarm Y occurs, contact the INL experiment manager
 - ✓ If Alarm Z occurs, contact the PNNL experiment sponsor
 - Responses to planned and unplanned events
 - ✓ What if a thermocouple fails?
 - ✓ What if the backup thermocouple fails?
 - ✓ What to do during planned reactor outages
 - ✓ What to do if the reactor scrams
 - ✓ What to do during unplanned reactor outages



Passive or Active Instrumentation

- Temperature is often a key parameter in irradiation experiments and modeling cannot account for departures from planned operations
- Active temperature measurement/control is preferable, but not always possible
 - Active control uses flowing mixtures of He/Ne or He/Ar in gas gaps to produce desired temperature at sample
- Passive temperature measurement methods exist
 - Melt wires
 - ✓ Include several different metals/alloys with a range of melting temperatures to bracket peak temperature
 - Thermal expansion devices (TEDs)
 - ✓ Stainless steel capsules filled with Na or other metal that is liquid at design temperature
 - ✓ Measurement of capsule strain after irradiation provides an indication of peak temperature
 - SiC
 - ✓ Swelling of SiC under neutron irradiation is a well-characterized function of effective irradiation temperature between 300°C and 800°C – valid for proton irradiation?
 - ✓ Effective temperature reflects the average temperature over the last 1 dpa or so

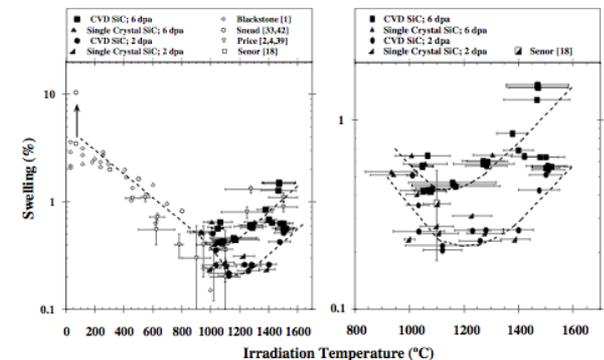
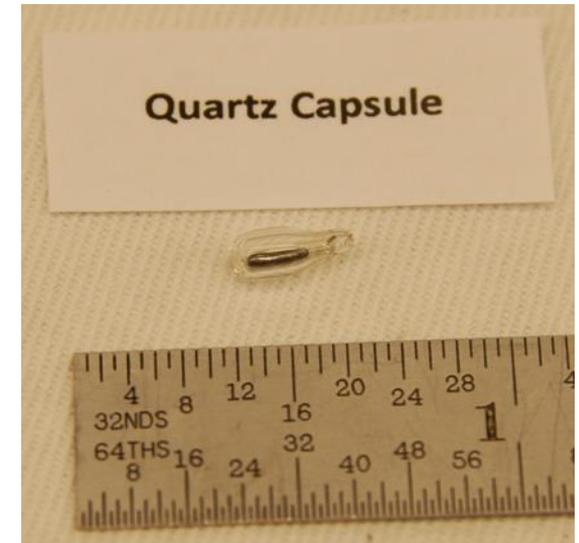


Fig. 1. Volumetric swelling of SiC as a function of neutron irradiation temperature.

Snead et al. 2007. *JNM*, 376-370:677.