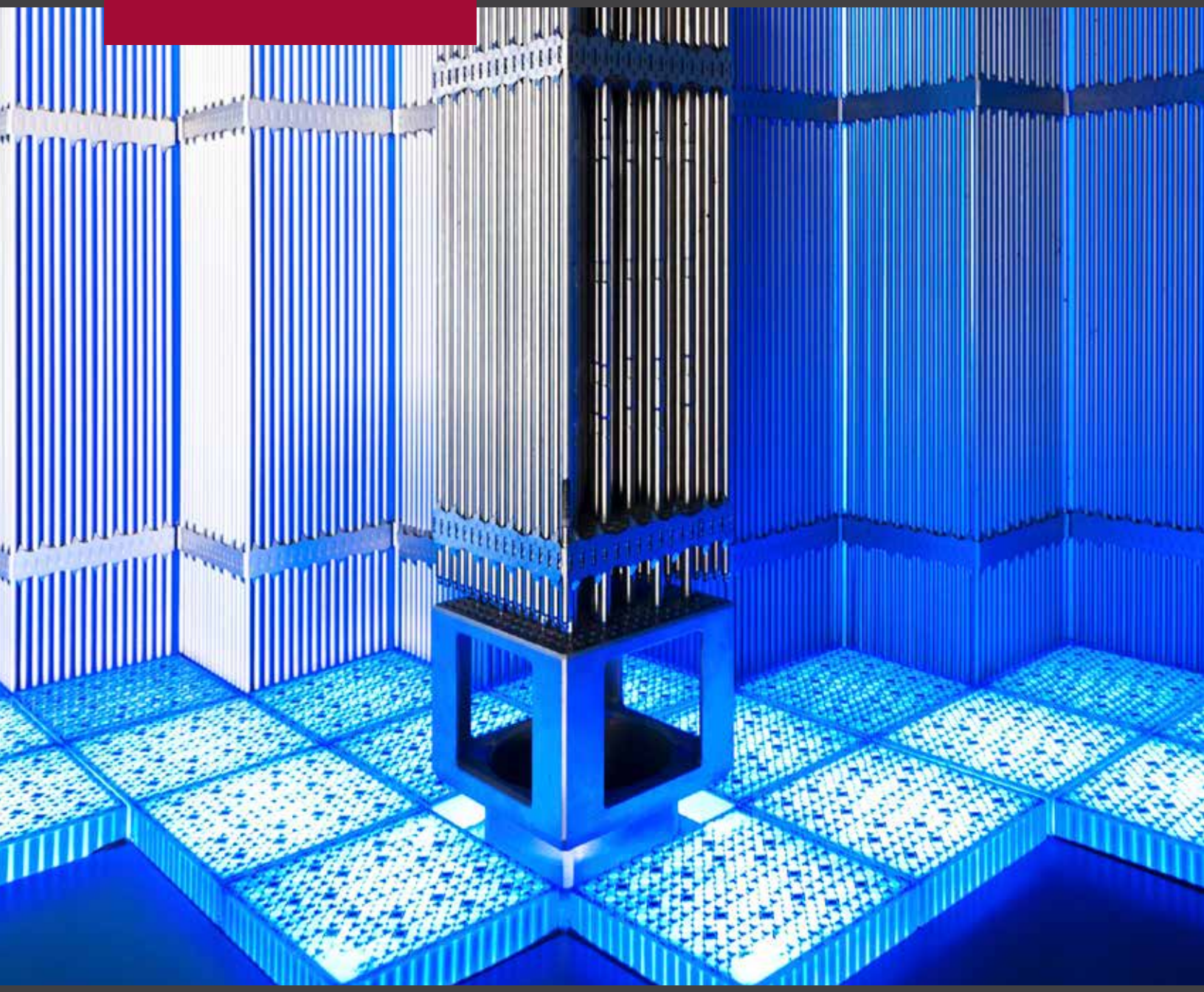
Structural Integrity Associates, Inc.™

NUCLEAR FUEL TECHNOLOGY

DEVOTED TO NUCLEAR | FUELED BY SCIENCE



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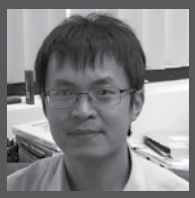
DEVOTED TO NUCLEAR













FUELED BY SCIENCE

NUCLEAR FUEL TECHNOLOGY

The Nuclear Fuel Technology Division is highly experienced in performance evaluations, material modeling, engineering analysis, and software development related to nuclear fuel behavior under normal operating conditions, off-normal transients, and postulated accidents. We have unique experience in all aspects of fuel reload design including core neutronics, thermal-hydraulics, transients and radiological dose analyses. Recognizing the importance of component quality on fuel performance and reliability, we have developed advanced capabilities in the technical assessment and fabrication surveillance of fuel rods and assembly components.

We welcome new challenges and urge you to contact us whenever the need arises **24/7/365**

1-877-4SI-POWER
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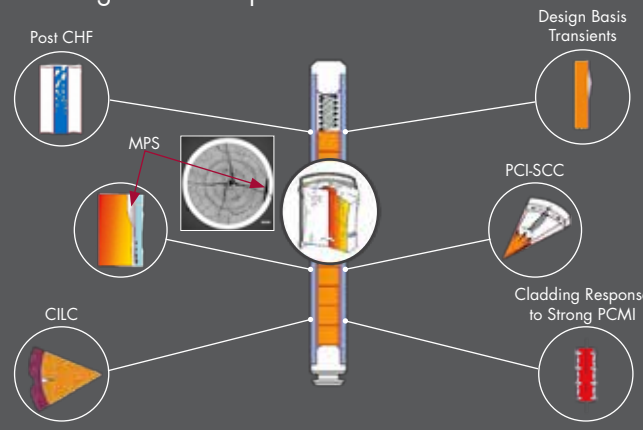
OUR NUCLEAR FUEL TECHNOLOGY SERVICES

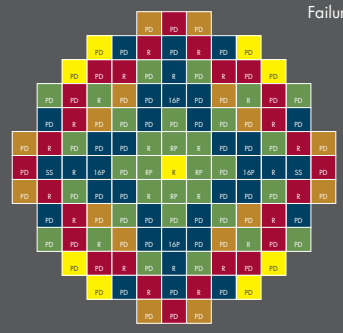
We provide practical and innovative engineering services to assess and improve the performance, reliability and safety of nuclear fuel and associated core components. We are industry experts in nuclear fuel behavior modeling and analyses. Our expertise extends to reload design and analyses as well as NRC licensing submittals for fuel driven modifications. We perform fuel engineering support for the entire fuel cycle from fuel fabrication to core design and analysis to plant operation and finally spent fuel storage and transportation.

SERVICES

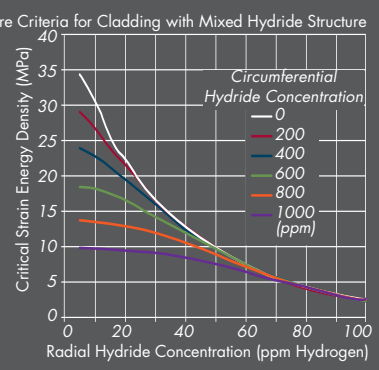
- **Modeling and Software Development for Diagnostic Evaluation of Critical Fuel Performance Related Issues**
  - Classic Pellet-Cladding Interaction (PCI), Stress Corrosion Cracking (SCC), and PCI Missing Pellet Surface (MPS)
  - Accidents: Reactivity Insertion Accident (RIA), and Loss of Coolant Accident Degradation (LOCA) Behavior Failed Fuel



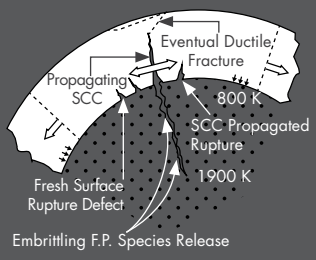
- **Reload Design and Plant Support**
  - Core Design
  - Thermal Hydraulics Analysis
  - Safety Analysis
  - Setpoint Analysis
  - Dose Analysis
  - Startup and Operations Support for Plant Maneuvers

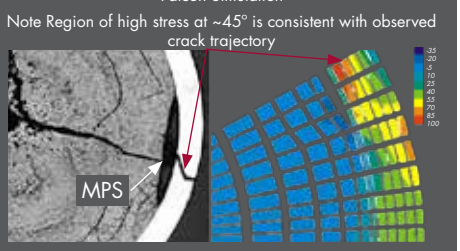


Example of fuel pattern that satisfies safety, economy, etc.

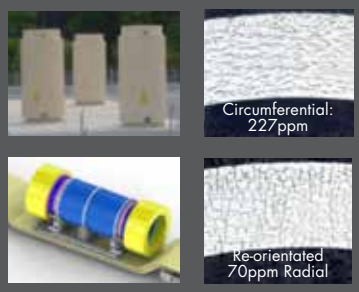


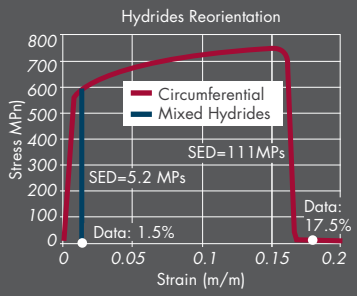
- **PCI-Risk-Free Power Operations**
  - Plant Start-up Power Ramping
  - Flexible Power Operations and Load Follow
  - Fuel Conditioning and Reconditioning
  - Operational Guidelines



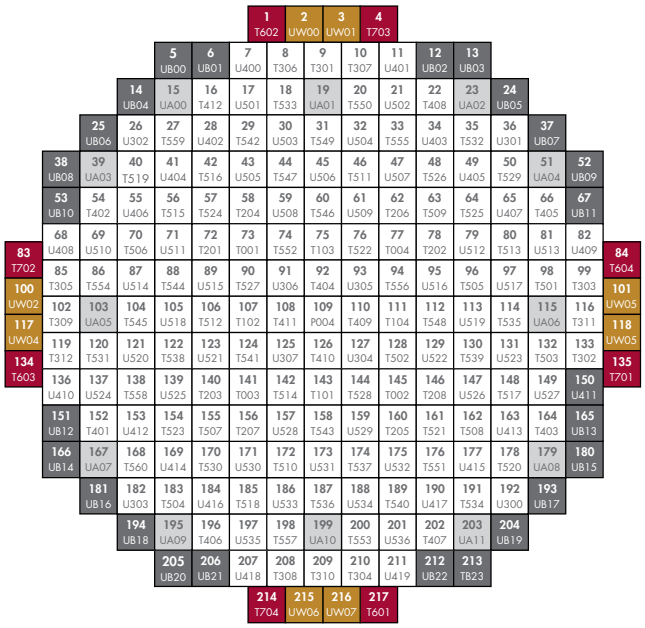


- **Licensing Support for Spent Fuel Dry Storage and Transportation**
  - Hydrides Reorientation
  - Fuel Rods Failure under Hypothetical Accidents





NUCLEAR FUEL DESIGN AND RELOAD SAFETY ANALYSES



CORE DESIGN OPTIMIZATION

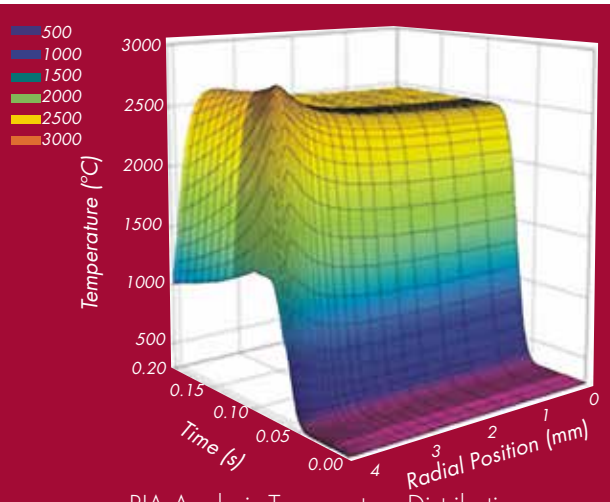
Traditionally, core design has been the exclusive area of expertise of fuel vendors. To manage fuel costs, utilities have recognized the value of independent core design and multi-cycle optimization. We have the experience to perform independent core design analysis and optimization resulting in:

- Significant fuel cost savings by improving fuel utilization
- Operational flexibility including reduced power operations, and load following
- Enhanced long term performance from multi-cycle optimization

RELOAD SAFETY ANALYSIS

The continued evolution of fuel designs, plant operating strategies, and performance goals in the power generation market demands that licensing and safety analysis of nuclear reactors be flexible and responsive. We have the analytical expertise to perform all aspects of fuel reload engineering including:

- Core thermal hydraulics, design basis transients, setpoints, and accident radiological dose analyses
- Licensing submittals to provide additional plant safety analysis margins and support power uprates, life extension and Fukushima related activities



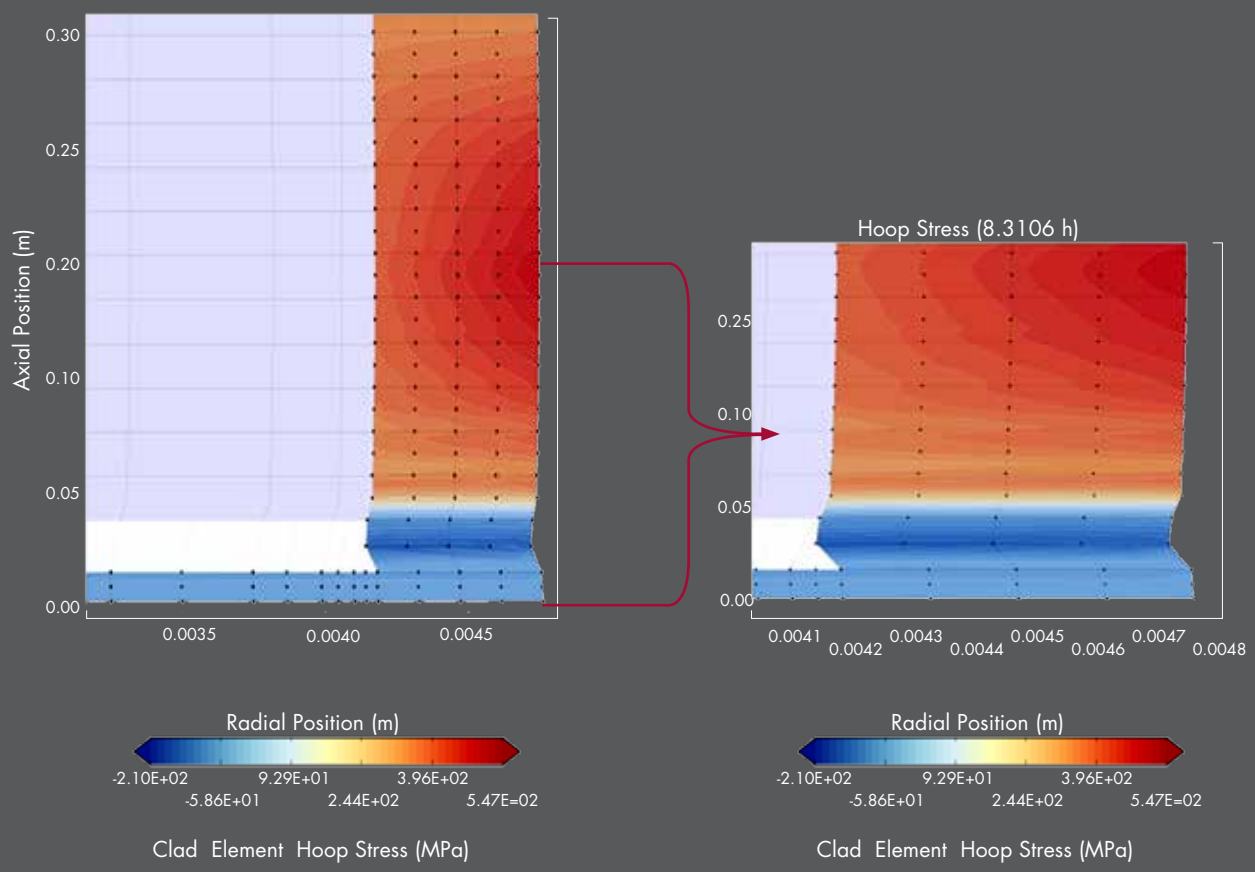
RIA Analysis Temperature Distributions

MULTIPLE FUEL VENDOR LICENSING AND ANALYSIS

Security of fuel supply is an increasing concern in the nuclear power industry. Additionally, fuel costs and engineering support can be improved by having multiple fuel vendors available to supply fuel. Domestic and international fuel vendors will compete for your fuel contracts. Independent fuel reload analysis allows use of fuel from multiple vendors and supports competition.

Our personnel have orchestrated licensing of multiple fuel vendors and fuel vendor transitions, including:

- Financial impact assessments of multiple fuel suppliers
- Optimized core designs for multiple fuel types
- Detailed mixed core thermal hydraulic and fuel performance analyses
- Impact assessments on existing reload analysis methodologies
- Independent review of fuel vendor specific reports and analyses



Rod Deformation; Cladding Stress Distribution

FUEL BEHAVIOR MODELING AND ANALYSIS

SI's Nuclear Fuel Technology (NFT) Division has developed and contributed to some of the most robust and cutting edge computational technology for fuel performance analysis in the industry for over 40 years under the sponsorship of research and governmental organizations such as EPRI and the Department of Energy (DOE).

- Development of power ramp rate restrictions and operational guidance for commercial utilities to mitigate fuel rod failure due to Missing Pellet Surface (MPS)-induced Pellet Cladding Interaction (PCI)
- Analysis for Crud-Induced Localized Corrosion (CILC)-affected BWR fuel during normal operation
- Key member of the Industry Task Force on Reactivity Initiated Accidents (RIA)
- Key participant in the Nuclear Regulatory Commission (NRC) Expert Panel that developed the Phenomena Identification and Ranking Tables (PIRT) review document for BWR Anticipated Transient Without Scram (ATWS) Power Oscillation Event, PWR Control Rod Ejection Accident (REA), BWR/PWR Loss of Coolant Accident (LOCA)
- Key technical participant for industry response to NRC rulemaking on RIA and LOCA
- Primary contractor to EPRI for development of Pellet-Cladding Interaction (PCI) Fuel Reliability Guidelines
- Leading participant in EPRI-sponsored programs related to
  - Flexible and Extended Reduced Power Operations (FPO, ERPO)
  - Assessment of proposed advanced and accident tolerant fuel (ATF) designs
  - Spent fuel rod integrity during handling and transportation

NUCLEAR FUEL PERFORMANCE CODE DEVELOPMENT

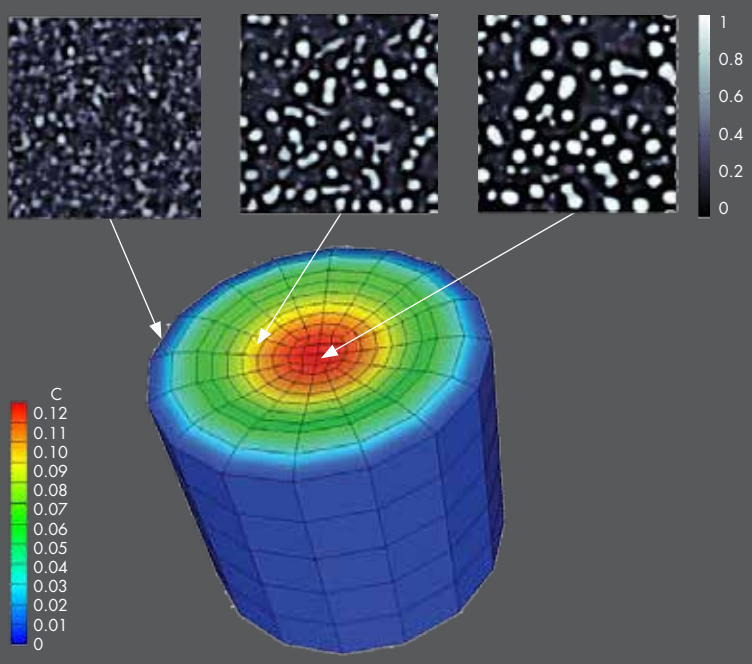
Our Nuclear Fuel group is the industry leader in fuel performance code development. Our staff has developed cutting edge fuel performance tools for EPRI and DOE and provided training and independent analyses throughout the industry in the Americas, Europe, and Asia.

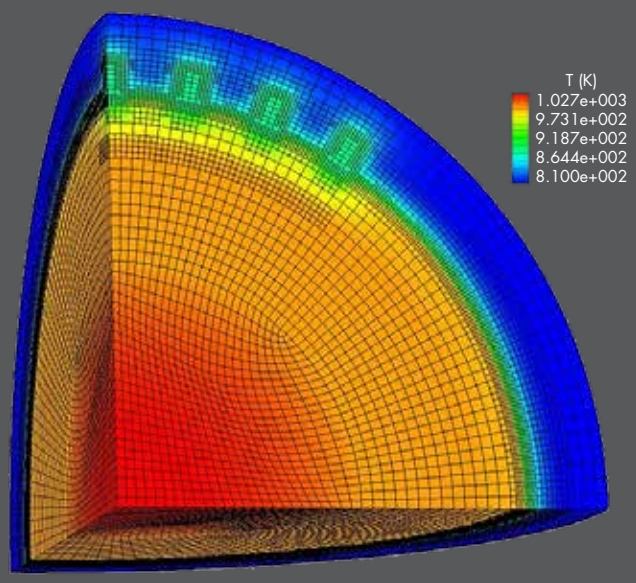
Under contract to EPRI, NFT pioneered the use of advanced thermo-mechanical techniques for fuel performance analysis in the development of the FREY code, the first fully 2D, thermo-mechanical, finite element (FE)-based nuclear fuel performance code for transient analysis. The FREY architecture was also used as the basis for the DEFECT code, a computational tool, unique in the industry, for post primary failure analysis and assessment for suppression of secondary fuel rod failures in BWRs.

The next significant fuel performance code developed by SI for EPRI was the Falcon code. Key Falcon items of interest are:

- Used for both steady state and transient analyses simultaneously providing the capability to address fuel rod behavior during normal operation, power maneuvers, and postulated accidents
- Applied to PCI SCC and MPS rod failure assessment, RIA, LOCA, FPO and ERPO

NFT is also now working on 3D, FE-based computational tools for fuel performance analysis and since 2012 has been contracted by the Department of Energy as a contributing developer to the NEAMS, BISON and Consortium for Advanced Simulation of Light Water Reactors (CASL) programs. Participation in these leading-edge programs demonstrate the wide-ranging experience and expertise of NFT staff and our contributions of critical technologies to the nuclear fuel industry.

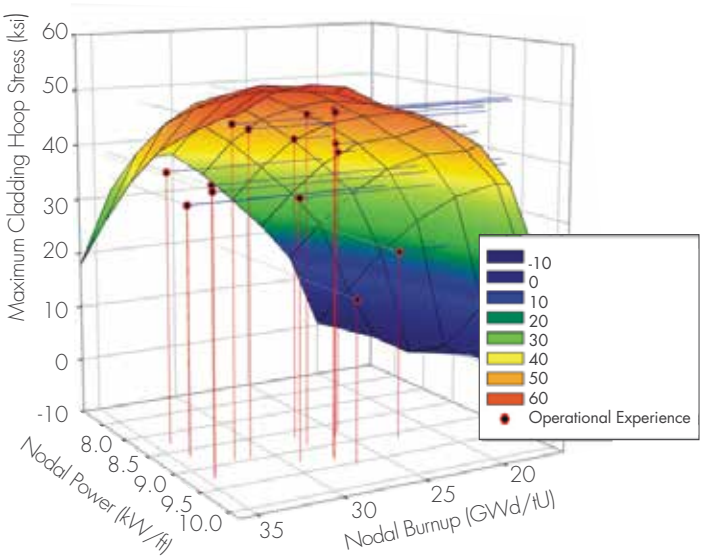




BISON Fuel Modeling

NUCLEAR FUEL TECHNOLOGY APPLICATIONS - PCI

NFT has provided pioneering expertise to the nuclear industry in the evaluation of Pellet-cladding interaction (PCI) fuel failures.

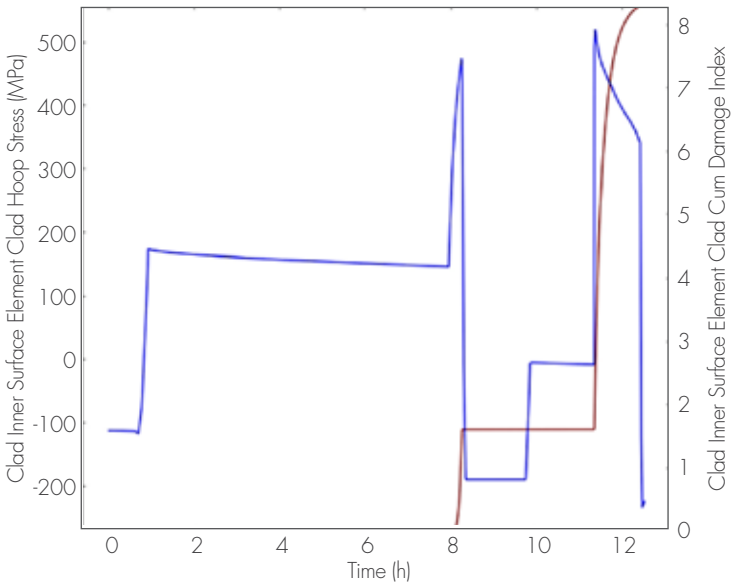


Power and burnup dependent bounding analysis

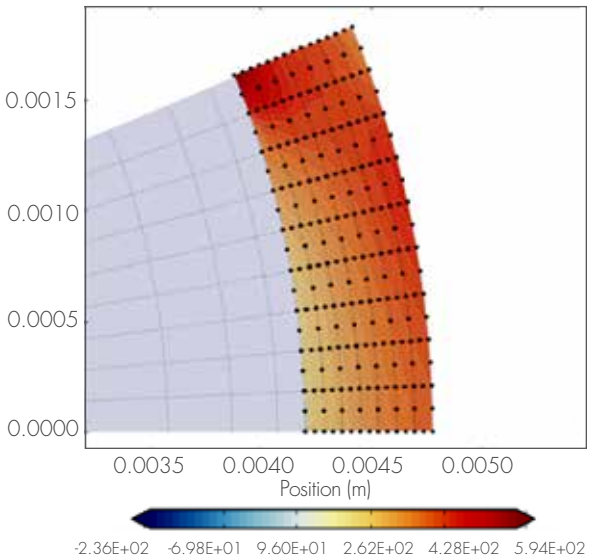
- NFT developed the computational tools and methodology to evaluate and mitigate potential fuel rod failures due to PCI and MPS-enhanced PCI in LWRs.
- Worked with utilities to assess margin to failure based on their current and proposed operating strategies including evaluation of startup strategies, alternative fuel designs, manufacturing defects, and equipment outages
- Provided operational guidance to mitigate and eliminate PCI-type fuel rod failures
- NFT was the primary contractor for EPRI that developed the fuel reliability guidelines for use by utility personnel and industry oversight organizations
- PCI failure mitigation in BWR and PWR fuel designs through the development of improved power maneuvering procedures

Based on this experience, NFT has developed and provides training seminars to utility staff to enhance their awareness and understanding of PCI-type failures.

Clad Inner Surface Hoop Stress (Avg) and Cum Damage Index History



Clad Element Hoop Stress (MPa)

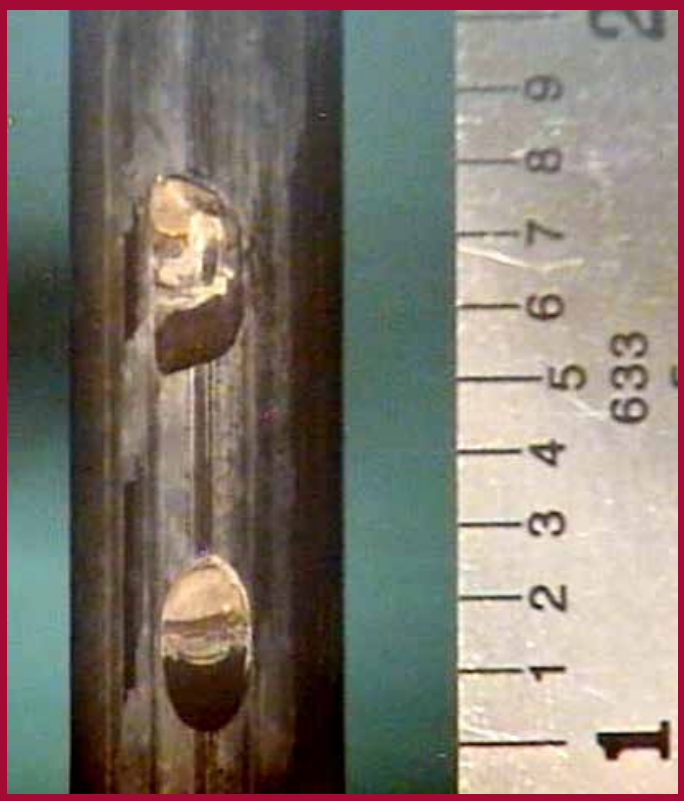


DEVELOPMENT OF INDUSTRY FUEL RELIABILITY GUIDELINES

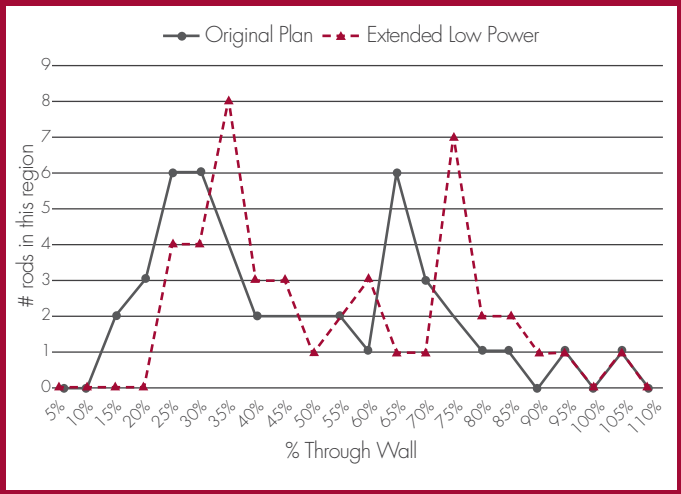
In support of the nuclear industry's initiative to eliminate fuel failures, we worked with the Electric Power Research Institute (EPRI) to develop the following important fuel reliability guidelines for use by utility personnel and industry oversight organizations:

- Fuel surveillance and inspection programs to identify and assess trends in key fuel performance characteristics for currently operating reactors, following changes in fuel design, manufacture and operation, or after anomalous plant operational conditions.
- Pellet-cladding interaction (PCI) failure mitigation in BWR and PWR fuel designs through the development of improved power maneuvering procedures.
- Grid-to-rod fretting fuel failure recommendations to eliminate failures through improvements in debris mitigation features in fuel designs, core design modifications, and fuel spacer grid design improvements.

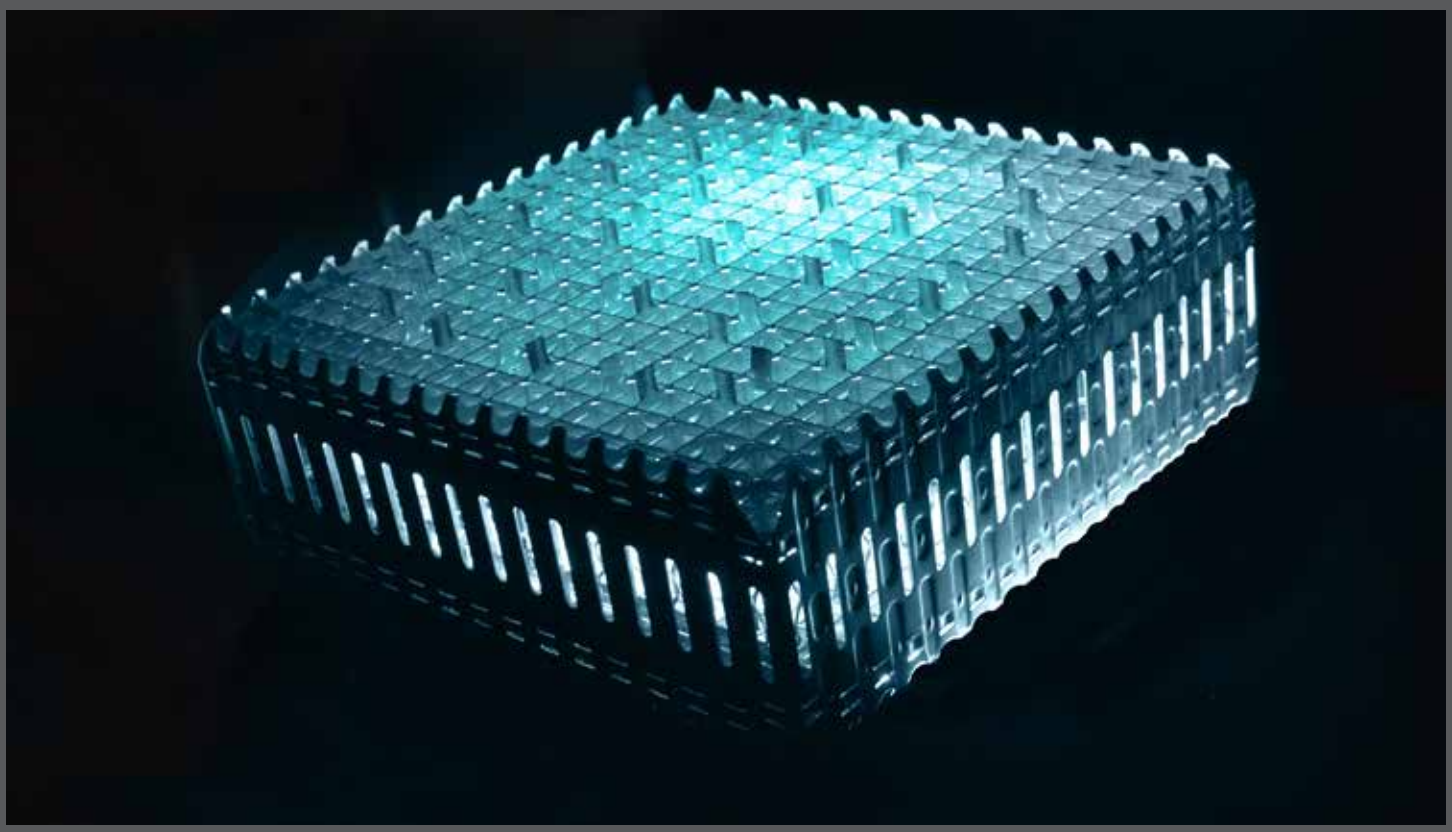
These guidelines have been used by Utility personnel and industry oversight organizations not only to enhance their understanding of the issues but to also assess and improve the performance of their fuel.



Grid to Rod Fretting Indication



Grid-to Rod Fretting Wear Trends - Assuming 3rd cycle increase from 600 to 670 days at flow



NUCLEAR FUEL MECHANICAL DESIGN

Whether to extend current capabilities or remedy in-core reliability issues, the risks of introducing new fuel design features or new materials can be quite severe. These risks include failure to meet performance or operational expectations, introduction of unexpected reliability issues, and in the worst case, fuel failures. Given these risks, it is imperative to independently assess supplier changes to existing designs and materials prior to introduction into the core. This third-party assessment includes review of:

- Supplier design packages
- Mechanical and seismic test requirements, criteria, and reports
- In-core performance databases
- Lead test program post-irradiation examination results
- Past performance of similar features

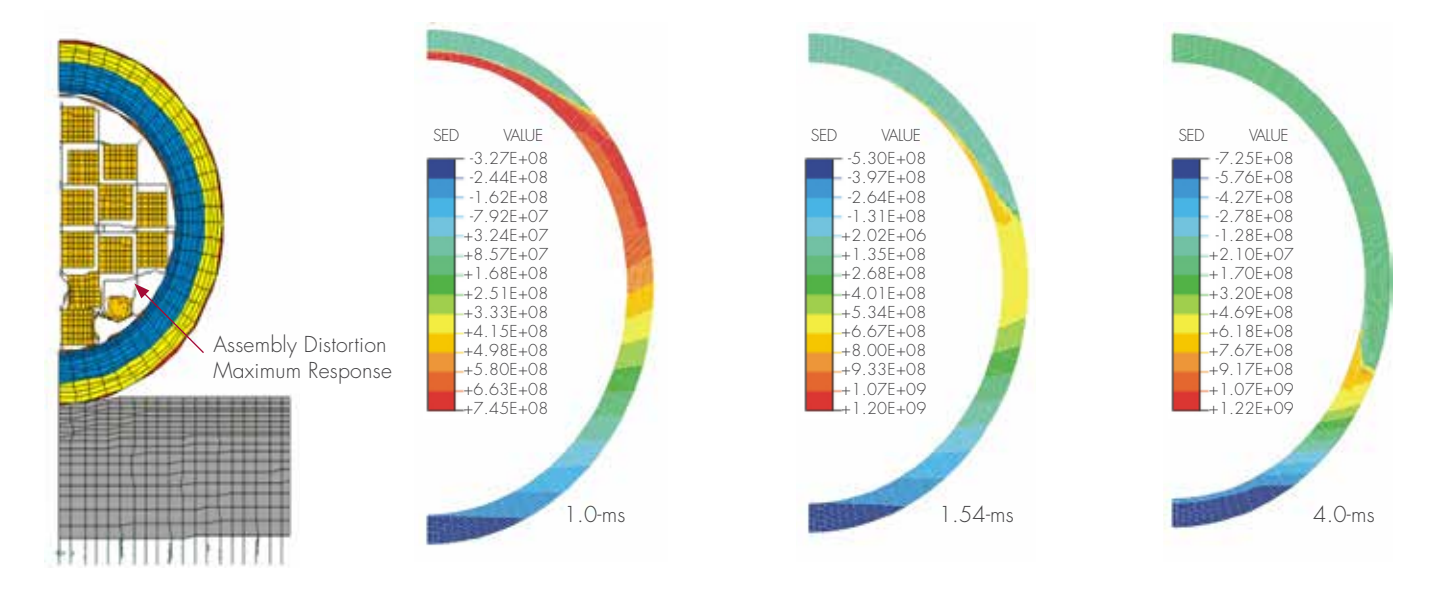
SI's unparalleled, specialized, global experience in this area includes design review for the following:

- Advanced BWR, PWR and VVER designs
- Structural design of fuel assembly and core components for an advanced reactor concept
- Material evaluations of advanced cladding alloys

SPENT FUEL STORAGE AND TRANSPORTATION

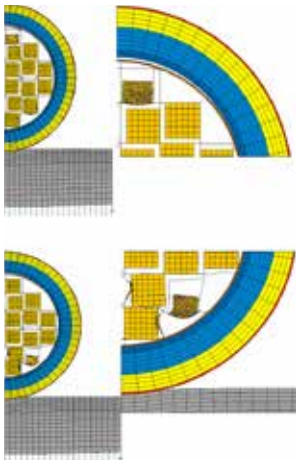
With the increasing frequency of nuclear plant shutdowns, decommissioning of power plant sites is becoming a new focus area in the industry. Decommissioning and emergency response reduction licensing submittals, spent fuel pool islanding and dry cask canister design verifications are becoming familiar terms at nuclear plant sites. Our staff have the knowledge and expertise to perform and review all fuel related analysis in this area, including dry cask storage loading patterns, heat load analyses and dose calculations, and safety analyses of spent fuel systems under storage and transport conditions prescribed in 10 CFR 71 & 72. In offering these services, we rely on our staff's extensive experience in spent fuel technology as described below.

The Structural Integrity Nuclear Fuel Technology Group began their spent fuel activities in the early 1990s as members of an expert team selected by SANDIA National Laboratory for the development of the well-known cask containment requirements report SAND90-2406, November 1992. Building on that report, the SI team, under contract to EPRI since the year 2000, have carried the research further to deal with high burnup fuel issues, developing methods to quantify threats to cladding integrity during drop accidents. Such threats stem from cladding loss of ductility during high-burnup operation and the evaluation of damage mechanisms, such as hydride re-orientation, during long-term dry storage. SI's research in this area, which is still continuing, has produced a large volume of original work, which include position papers submitted to the NRC for review on topics such as the characterization of failure mechanisms and associated failure criteria, and the response analysis of spent fuel systems subjected to normal and hypothetical accident conditions as prescribed in 10 CFR 71. The following is a synopsis in pictures that selectively highlights SI's spent fuel experience.

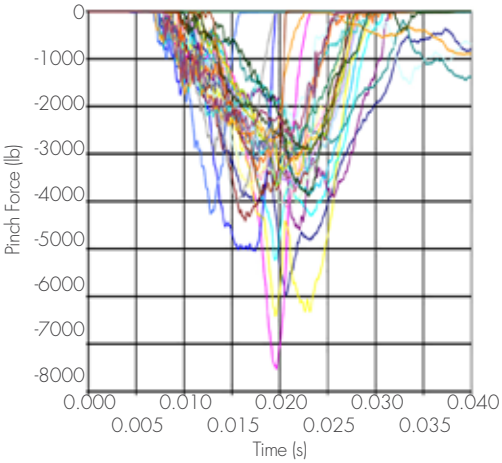


Hypothetical Transportation Accident: 9-m Cask-Drop
Guide Tube Response: Green Color Indicates the Extent of Fracture

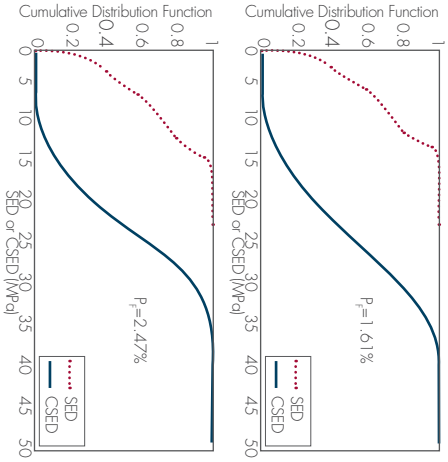
Spent Fuel Response Analysis & Failure Probabilities Under 9-m Drop



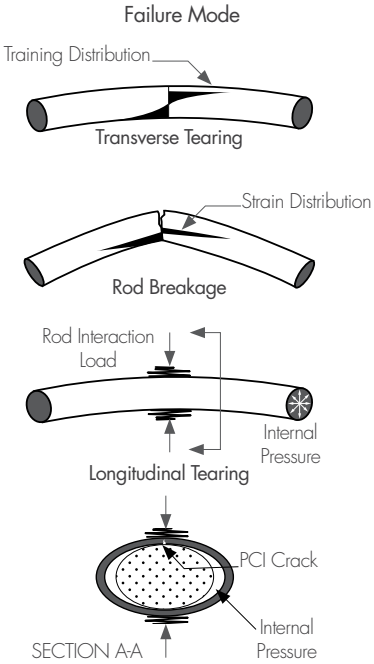
Cask Drop Simulation showing assembly Reconfigurations



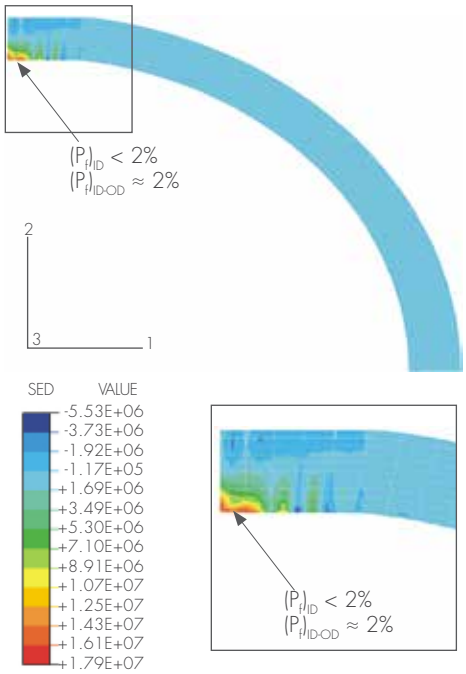
Maximum Pinch Force Time Histories



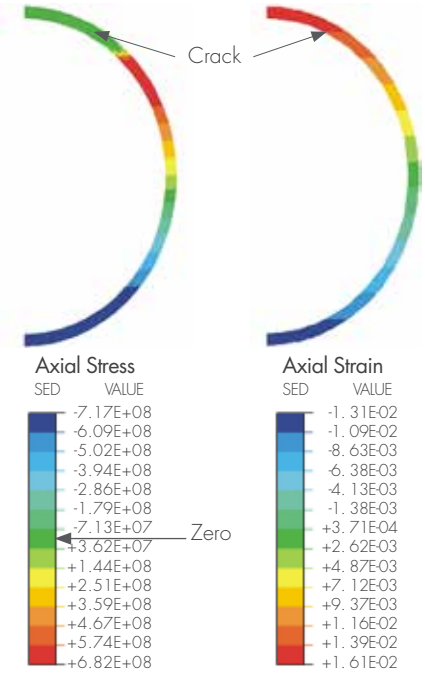
Failure Probability IFBA/Standard Fuel



Fuel Rods Failure Modes During Cask Drop

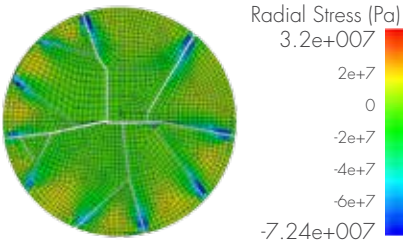


Cladding Failure Probabilities at ID & OD



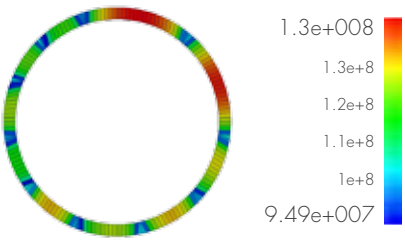
Guide Tube Partial Failure

Spent Fuel with Fuel-Cladding Bonding In Dry Storage

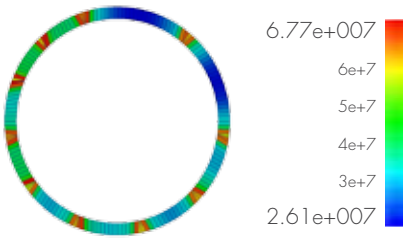


Fuel Radial Stress at 400°C & Pressurized Cracks

Radial Stress in Fuel Pellet with Pressurized Cracks



Cladding hoop stress at 400°C at zero hold time



Cladding hoop stress at 400°C After 60-day hold

Cladding Hoop Stress During 60-day Hold at 400°C after Vacuum Drying

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