

MATERIAL RESILIENCE IN HARSH SERVICE CONDITIONS

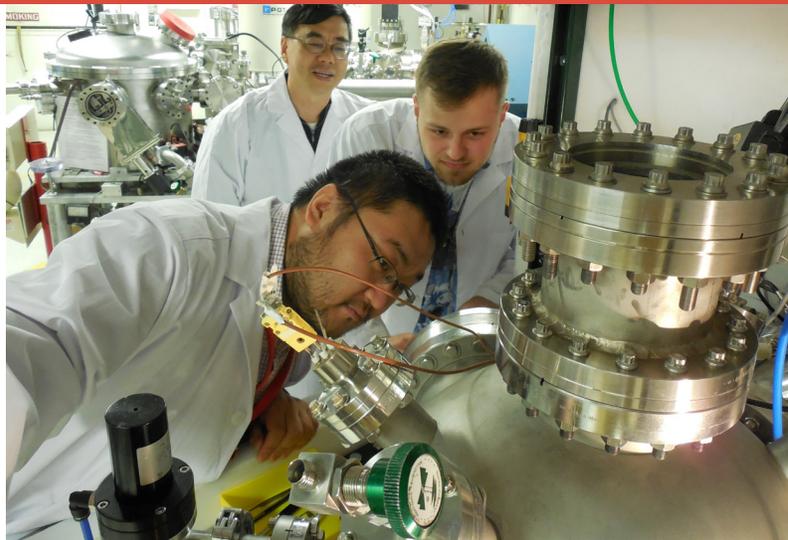


Resilience describes the attributes of a material that allow it to withstand or resist detrimental environmental effects degrading properties and performance. In service, materials may experience harsh or extreme conditions, but even modest thermal or load conditions experienced over a long period can degrade performance. Thus, the National Nuclear Security Administration mission requires predictive understanding of materials performance in harsh and extreme conditions over long periods. This is particularly true for applications in which replacement is impractical, impossible, or costly.

This area of leadership addresses the evolution of material properties in environments that include static and dynamic stress, radiation, and chemical or thermal extremes. A particular focus is on situations when environments coexist or for which collection of experimental data is challenging or impossible. The capability to predict and control the nature and evolution of properties to allow designing resilience is a crucial aspect of mission success in national nuclear, global, and energy security.

Los Alamos Leadership in Material Resilience in Harsh Service Conditions

In the stockpile, materials must maintain function over the lifetime of each weapon. In storage, this involves long periods of self-irradiation and modest thermal cycling. During normal service, materials experience a range of thermal, radiation, and load cycles over long time periods. During service lifetimes or abnormal events, materials may experience multi-particle radiation (neutrons, x-rays, γ -rays), shock, or thermal effects over short time scales. Thus, resilient material response is required over long periods and over a wide range of compounding conditions. Given our leadership in space-based detection for nonproliferation, our space technology places unique demands on resilience. Detectors and electronics in satellites are typically inaccessible after launch but must remain functional over multi-year service lifetimes during extreme thermal cycling and continuous exposure to high-energy cosmic rays. Shielding for spacecraft must be resilient to the effects of re-entry and reuse. Lastly, many energy security technologies, e.g., nuclear, fossil, and renewables, require material resilience under harsh conditions. Nuclear energy requires resilience in fuels and cladding. In fuel, maintaining thermal conductivity is a key aspiration. In



Designing and predicting the lifetime of materials under complex and harsh environments is a critical need for Los Alamos National Laboratory's mission areas, particularly nuclear weapons and nuclear energy. Here, Lab researchers perform an ion irradiation to test the radiation tolerance of a potential nuclear energy cladding material.

Materials for the Future

The Los Alamos National Laboratory Materials for the Future strategy derives from our vision to support the Laboratory's national security mission drivers.

We pursue the discovery science and engineering for advanced and new materials to intentionally control functionality and predict performance relevant to ensuring the success of the Lab's missions.

To deliver on our missions, our materials strategy builds on materials science and engineering, enabling the necessary Laboratory leadership in seven key areas:

- Complex Functional Materials
- Material Resilience in Harsh Service Conditions
- Manufacturing Science
- Actinides and Correlated Electron Materials
- Integrated Nanomaterials
- Energetic Materials
- Materials Dynamics

cladding, structural integrity is required to limit radioactive release from transmutation products. In nuclear waste forms, structural integrity and stability over geologic intervals is required. A key challenge is resilient response in the face of a variety of path-dependent histories that include typical as well as accident conditions. In fossil fuel and geothermal industries, resilience is valued in upstream drilling and production applications, where functionality must be maintained at high pressures and temperatures. In downstream applications, corrosive environments resulting from acids are common. Although the operating temperatures are considerably lower for fuel cell technologies than for nuclear or fossil, the operating conditions are still quite extreme for the types of materials used in fuel cells.

A particular challenge for Los Alamos is the prediction of performance and development of new materials with controlled functionality for extreme environments. Since historical full-scale hydro-nuclear testing is no longer available, we must rely on developing unique advanced strategies to integrate and extrapolate properties from scaled and surrogate separate effects testing into full-scale, fully integrated tests to generate data for models of a particular environment. Therefore, the science of “harsh environment” is determining the material and geometry choices to ensure intended function based on models using data from measurements of scaled, surrogated, separate effects testing. For example, neutron and photon heating, in a pulsed fission spectrum environment, can be quantified in a pulsed reactor such as the Annular Core Research Reactor at Sandia National Laboratories to qualify a large integrated design, while facilities such as the Z Pulsed Power Facility at Sandia, the National Ignition Facility at Lawrence Livermore National Laboratory, and the Advanced Photon Source at Argonne National Laboratory can be used to measure the effect of neutron bombardment and x-ray impingement.

However, all these facilities require that experiments be scaled, extrapolated, and integrated to the real environment. The science of scaling, extrapolation, and integration requires deep understanding of the microscopic physics and scaling to the bulk. The future of these analyses will involve taking scaled surrogate measurements and determining how these measurements can be extrapolated to be used in complex models of the real behavior.

Key Science Questions

- How can we predict evolving properties in inaccessible harsh or extreme conditions using scaled, accelerated, or surrogate tests?
- How does fast rise-time pulsed radiation affect materials functionality?

- How can sub-mesoscale modeling improve performance prediction of fuels and cladding under irradiation and what new approaches can accelerate certification of new fuel types?
- Can instrument performance predictions be improved in a space environment and can advanced manufacturing offer new relevant technology options for space applications?
- What materials development options exist for improved function in materials that operate at elevated pressure and temperature and harsh chemical environments?

10-year End State

We will develop new models and synthesis techniques to design new materials with greater resilience under these extreme conditions with predictable performance. We envision the development of unique experimental facilities that can generate multiple, simultaneous harsh environments with in situ diagnostics to understand the kinetic response of materials under these conditions. This will be critical for validating our models and giving us confidence to extrapolate to regimes we cannot access. A center of excellence for the science of applying scaled, surrogate, and separate effects testing to understanding of complex phenomena is envisioned that will enable integrating processing-structure-properties-performance capability in design, certification, and re-use. Specifically, we expect Los Alamos models to be able to predict materials lifetime based on accelerated testing in weapons applications and nuclear energy, space, and renewable energy applications.

For more information, please see materials.lanl.gov or send email to materials@lanl.gov.



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