Advanced LWR Nuclear Fuel Cladding Development

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Background

The Advanced Light Water Reactor (LWR) Nuclear Fuel Development Research and Development (R&D) Pathway encompasses strategic research focused on improving reactor core economics and safety margins through the development of an advanced fuel cladding system. To achieve significant operating improvements while remaining within safety boundaries, significant steps beyond incremental improvements in the current generation of nuclear fuel are required. Fundamental enhancements are required in the areas of nuclear fuel composition, cladding integrity, and fuel/cladding interaction to allow improved fuel economy via power uprates and increased fuel burn-up allowance while potentially improving safety margin through the adoption of an "accident tolerant" fuel system that would offer improved coping time under accident scenarios.

In a staged development approach, the LWRS program will engage stakeholders throughout the development process to ensure commercial viability of the investigated technologies. Applying minimum performance criteria, several of the top-ranked materials and fabrication concepts will undergo a rigorous series of mechanical, thermal and chemical characterization tests to better define their properties and operating potential in a relatively low-cost, nonnuclear test series. A reduced number of options will be recommended for test rodlet fabrication and in-pile nuclear testing under steady-state, transient and accident conditions.

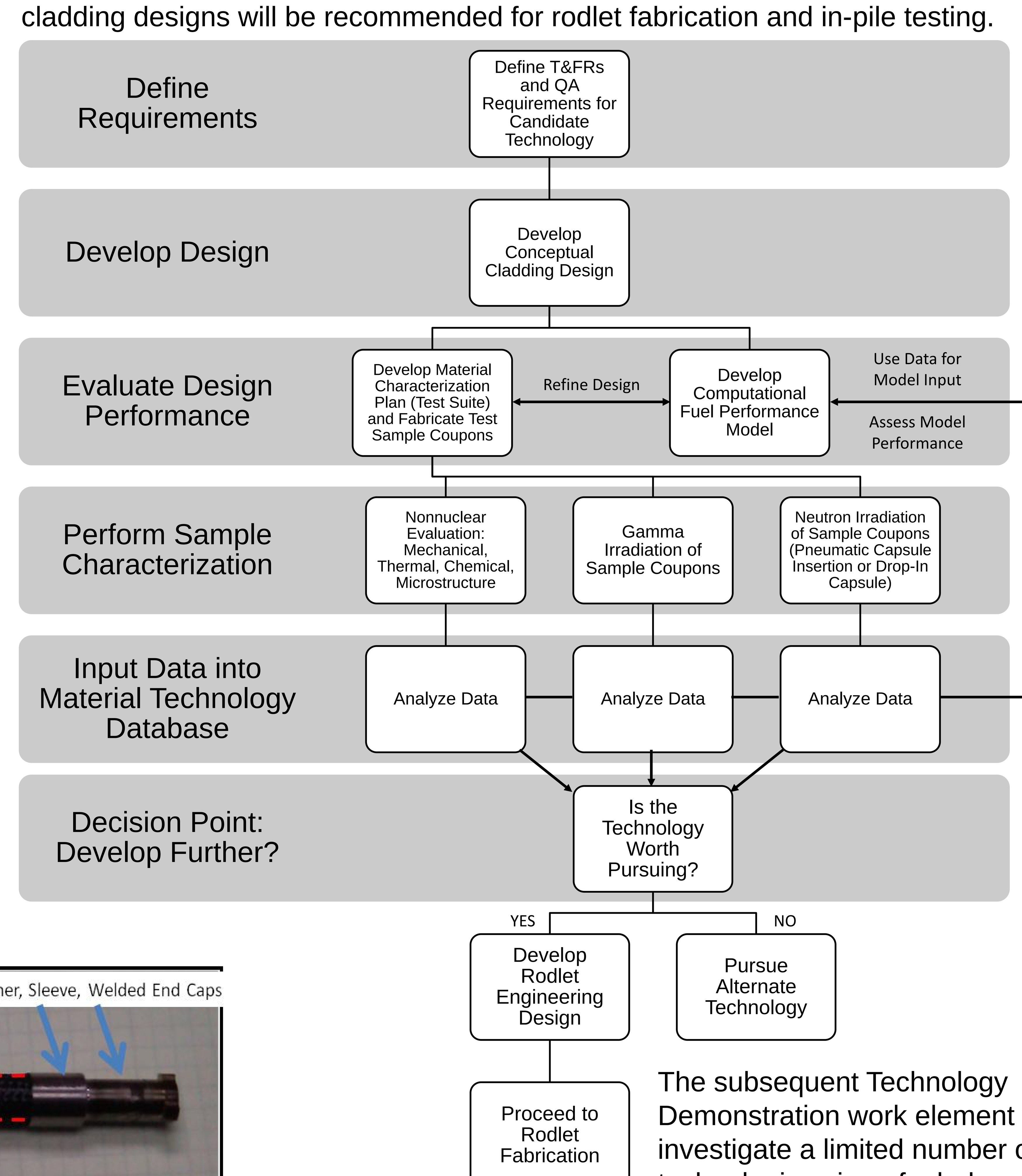
Cladding Options

Recent investigations of potential options for "accident tolerant" nuclear fuel systems point to the potential benefits of silicon carbide (SiC) cladding. SiC is available in both alpha and beta phase and in various forms, including monolithic, fiber, ceramic matrix composites, etc. Each form and fabrication technique results in varied mechanical strength, thermal properties, chemical properties, and radiation resistance.

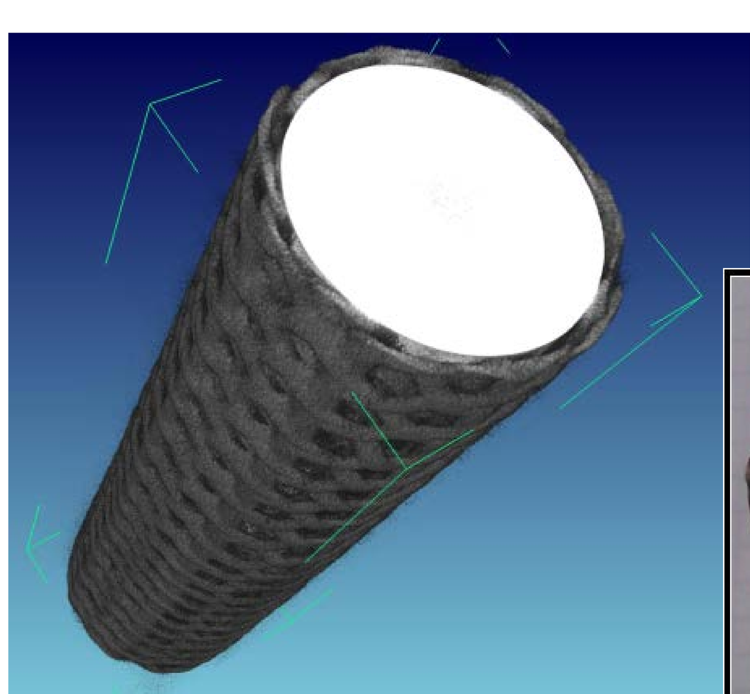
The two primary design concepts utilizing SiC composites considered for LWR cladding include fully ceramic SiC cladding and ceramic / metal cladding. This development program will consider all SiC fiber (SiC_f) ceramic matrix composite (CMC) cladding, fully ceramic cladding that incorporates SiC CMC and monolithic SiC layers and SiC CMC – metal hybrid cladding (SiC CMC over an inner metallic liner tube) will be considered in this development program.

Technology Development & Design

Technology Development work will focus on conceptual cladding design and preliminary testing (screening) of identified leading cladding technologies. A suite of materials characterization tests and property measurements will be conducted to fill gaps in the technology database for each candidate material and cladding design. This data will, in turn, be used to refine the modeling simulations of the fuel-clad system under nominal and off-nominal reactor conditions, and modeling results will be integrated with the conceptual design process. Conceptual fuel rod designs for each advanced cladding option will undergo preliminary analysis and review in anticipation of developing an engineering design. Technology development tests will focus on sample coupons and short cylindrical sections to acquire the necessary material properties and preliminary performance data. Based on characterization results and performance data, a limited number of cladding designs will be recommended for rodlet fabrication and in-pile testing.

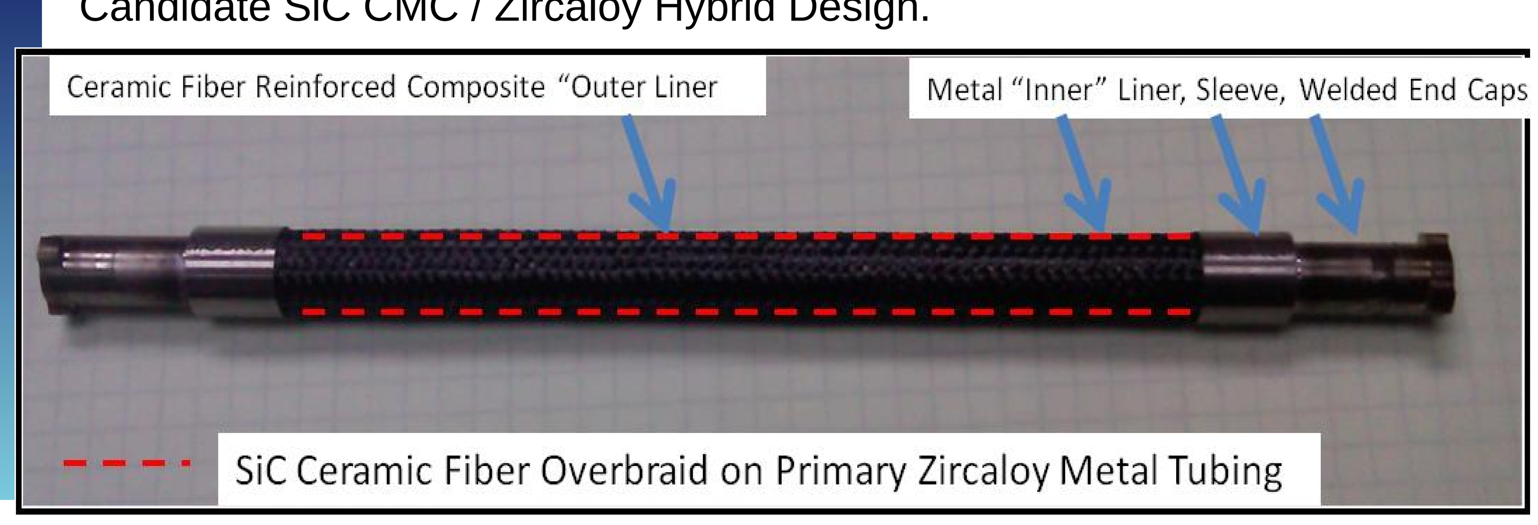


The subsequent Technology Demonstration work element will investigate a limited number of technologies via unfueled and fueled rodlet fabrication, characterization and irradiation at steady-state, transient and accident conditions.



Three dimensional reconstruction of SiC CMC rodlet geometry using X-ray tomography techniques.

Candidate SiC CMC / Zircaloy Hybrid Design.



The development of SiC CMC fuel cladding, supported by advanced tools and knowledge to speed new fuel deployment, could provide improved safety margins, reliability and economics.

SiC CMC selected for:

- High temperature stability with strength maintained well above 1500°C
- Low chemical reactivity
- Low neutron absorption (~20-30% less than Zr)
- Low corrosion rates
- High hardness can prevent fretting induced failures
- Reduced exothermic reaction with steam at high temperatures reduces hydrogen generation relative to zirconium-based cladding
- Improved water chemistry options for balance of plant optimization
- Database on behavior in a nuclear environment from fusion program

SiC CMC Development Issues:

- Robust end cap seal for hermeticity
- Brittle behavior (manufacturing, transport, seismic events)
- Cost and manufacturability at commercial scale
- Pellet to Clad interaction and behavior in nuclear environments, including accidents and failure modes, needs additional analysis

Related References

DOE Office of Nuclear Energy, *Light Water Reactor Sustainability Program, Advanced LWR Nuclear Fuel Cladding System Development: Technical Program Plan*, INL/MIS-12-25696, Rev. 0, April 2012.

I.J. van Rooyen, G.W. Griffith and J.E. Garnier, "Testing Results and Systems for Advanced Nuclear Fuel Materials," poster presentation at 3rd Intl Conf on Plant Life Management (PLIM) for Long Term Operations (LTO), Salt Lake City, UT, May 2012.