Lightbridge Enfission framatome

Lightbridge Fuel™ Development Program

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Meeting Purpose

- Introduce Enfission organization and key elements of the Lightbridge Fuel design
  - Preliminary design information and representative performance characteristics provide context for discussion of the project plans
  - Not intended to be a technical discussion of the fuel design
- Present Enfission's project plans, including design, testing, fabrication, and licensing
  - High level presentation of overall fuel development project. Subsequent NRC meetings and engagements will address specific licensing topics in more detail.
  - Affirm that the proposed project plan represents a feasible path toward licensing the fuel design and associated licensed activities
  - Discuss appropriate NRC engagements during the project to ensure project success

Meeting Agenda

- Enfission joint venture
- Project goals
- Key design elements of Lightbridge Fuel
- Project plan
  - Milestone schedule
  - Design process
  - Test program
  - Fabrication plans
  - Licensing plans

Enfission Joint Venture

- Enfission LLC is a 50-50 joint venture of Lightbridge Corp. and Framatome Inc.
  - Established January 2018 to develop and commercialize Lightbridge Fuel
  - Utilize Lightbridge and Framatome global fuel design and fabrication expertise
  - Fuel to be fabricated in Richland, WA
- Industry support
  - Nuclear Utility Fuel Advisory Board

Dominion DUKE ENERGY. Exelon Generation. SOUTHERN COMPANY

  - NuScale provided letter of support for Lightbridge's DOE FOA application

"NuScale believes commercialization of the Lightbridge fuel will be of significant benefit to NuScale"

Project Goals

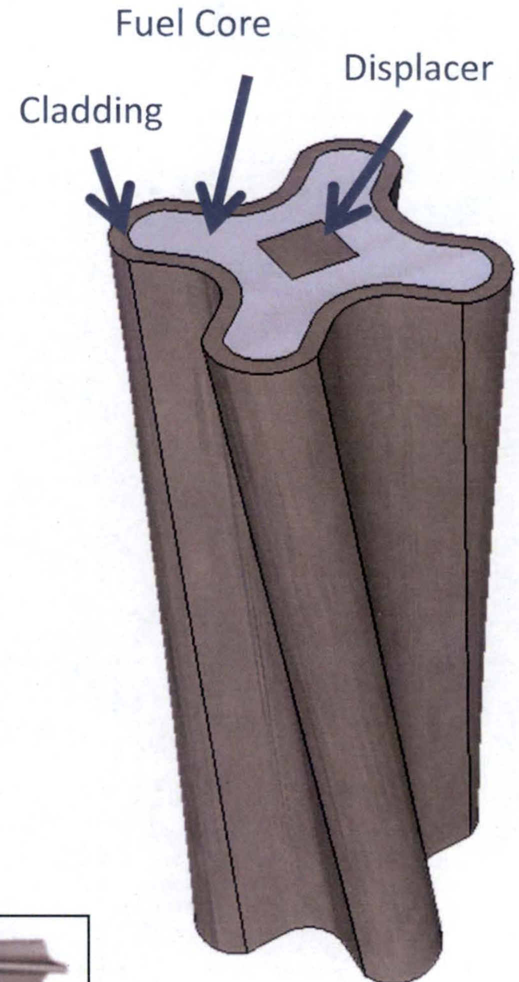
- Design and demonstrate Lightbridge Fuel, initially compatible with 17x17 US PWRs, that provides improved fuel cycle economics and meets or exceeds the safety performance of conventional fuel
- Deliver product to market utilizing a progressive, tiered demonstration of fuel safety that includes irradiation of samples in a test reactor, lead test rods, and lead test assemblies
- Develop and license fabrication and shipping capability for delivery of required fuel development products

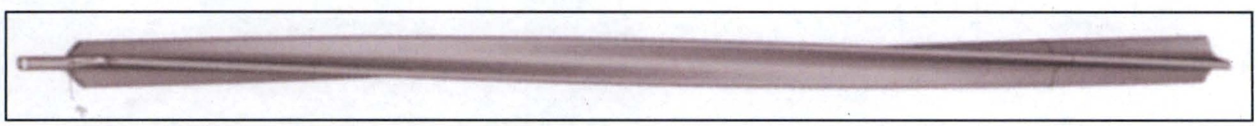
Key design elements of Lightbridge Fuel

The following information regarding the Lightbridge Fuel design is preliminary. Key elements of the fuel design are presented here to provide context for the discussion of project plans and fuel licensing activities.

Key Design Elements: Rod Design

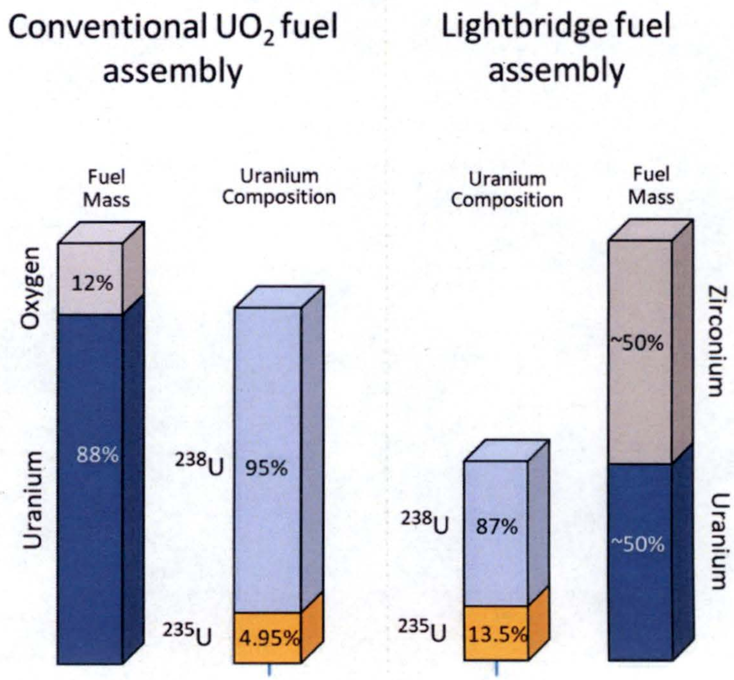
- Solid Metallic, helically-twisted, four-lobed fuel rod
  - Unique composition and geometry provide significant advantages compared to conventional fuels
- Three-component fuel rod:
  - Alloy fuel core (δ-phase UZr_2) experiences limited growth
  - Central displacer reduces centerline temperature
  - Cladding is metallurgically bonded to fuel core; no plenum or gas gap
  - Burnable poisons can be included internal to the fuel rod
- Helical-cruciform geometry
  - Increased surface area for heat transfer
  - Circumscribed diameter = pin-to-pin pitch
  - Fuel rods are self-spacing, i.e. no grids





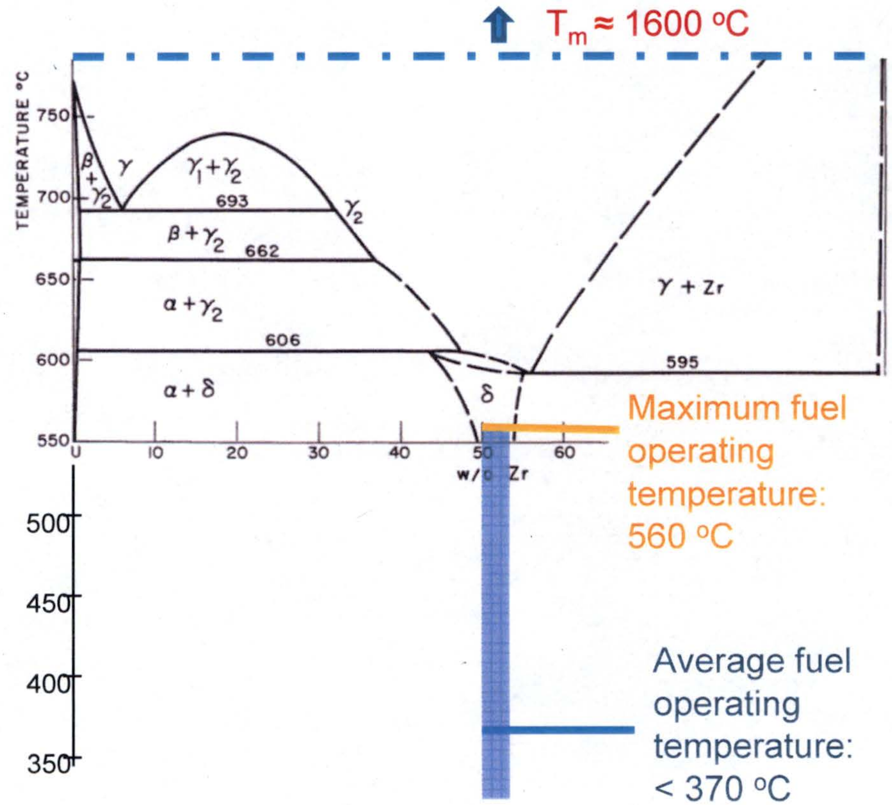
Key Design Elements: Greater than 5% Enriched Fuel

- Fuel enriched up to 19.7%
  - Reduced U volume
  - Fissile atom density similar to conventional fuel
  - Reduced fissile Pu production
- Reduced proliferation risk:
  - U enrichment <20% cannot be used for weapons purposes
  - Pu from Lightbridge Fuel is not suitable for nuclear explosive devices due to high ^{238}Pu concentration
- Regulatory considerations:
  - Part 70/71 licensing action required for fabrication, transportation
  - Part 50 licensing action considering the equivalent reactivity of UZr_2 compared to UO_2



Key Design Elements: Material Behavior

- Absence of α-U dramatically reduces irradiation-induced fuel swelling
- Low operating temperature limits diffusion, reducing the potential for FCCI-related failures
- Fission gases behave like solid fission products and remain where they are created; limited bubble formation and no gas accumulation for release in the event of cladding failure
- Atomic volume increase of 0.3% during δ - γ transition



Uranium-Zirconium phase diagram. "Constitution of the Uranium-rich U-Nb and U-Nb-Zr systems", Dwight & Mueller, ANL-5581 (modified).

Key Design Elements: Rod Spacing

Lightbridge Fuel Rod Cluster

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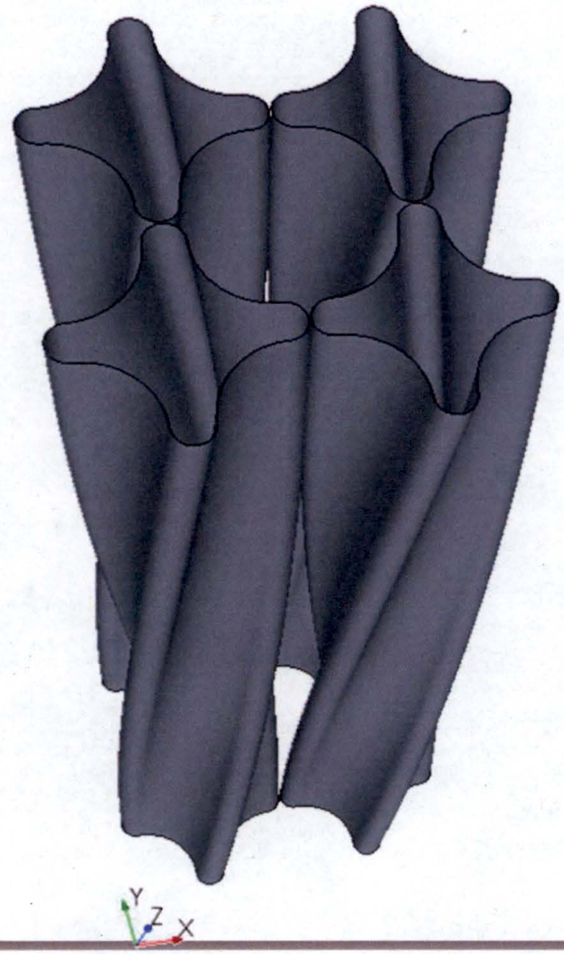

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Key Design Elements: Rod Integrity

- **Metallurgical bond** between fuel components significantly reduces cladding breach due to fuel-cladding mechanical interactions
- **Absence of spacer grids** eliminates grid-to-rod fretting and reduces the potential for debris fretting; also reduces the assembly pressure drop
- **Increased cladding thickness** at lobes increases the durability of the fuel at the contact points
- **Absence of fuel-clad gap** eliminates the mechanism for widespread coolant-cladding interaction on the inner cladding surface
- **No rod internal pressure issues**
- **Fuel rod extrusion process** eliminates several possible sources of manufacturing defects (e.g., pellet chipping, fuel column gaps, etc.)

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Unirradiated manufacturing demonstration rod with a tri-lobe design of similar composition.

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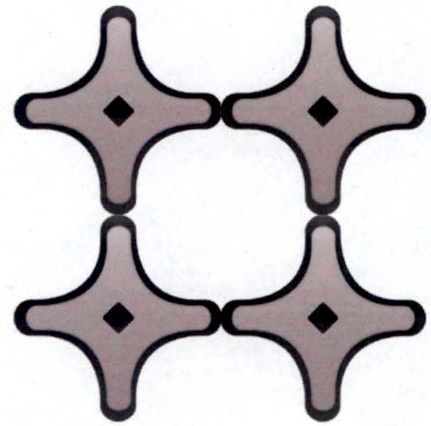
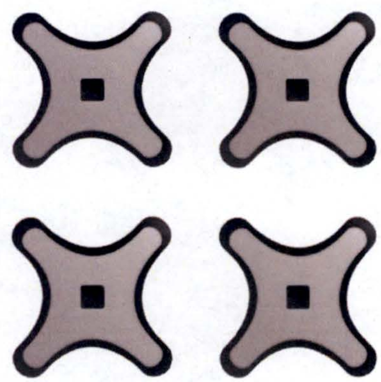
Key Design Elements: Fuel Assembly

- Fuel rod surface area is ~35% greater than cylindrical fuel
  - CHF testing planned to determine magnitude of benefit from enhanced surface area and geometry
- Helical twist allows for self-spaced fuel rods and inherent coolant mixing in fuel bundles
- Fuel assemblies require no mixing grids
  - ΔP_{core} reduced by ~50%
  - Major source of debris trapping eliminated
  - Coolant mixing is continuous along the length of the fuel rod and mitigates the development of hot spots



Self-spacing Plane



Half-Rotation Plane

Key Design Elements: Fuel Assembly

Lightbridge Fuel Assembly Cross-section

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Key Design Elements: Fuel Assembly

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Key Design Elements: Fuel Assembly

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Operating Experience with Icebreaker fuel

- Lightbridge Fuel is derived from the Russian maritime reactor fuel
  - Uranium-zirconium alloy fuel composition with high thermal conductivity
  - High power density
  - Ability to withstand high burn-ups in water cooled reactor
- Maritime reactor fuel experience
  - Irradiated ~3,100 fuel assemblies
  - Average burn-up ~ 200 MWd/kgHM
  - Nominal irradiation period – up to 7 years
  - Length of operation at nominal power – 30,000+ hours

Expected Performance

- Thermal hydraulic benefits
  - Beneficial decrease in fuel assembly pressure drop
  - Increased heated/wetted perimeter and associated lower average heat flux
  - High thermal conductivity, improved performance under postulated accident conditions

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- Mechanical benefits
  - Precludes challenges to fuel integrity associated with pellet-clad system
  - Reduced likelihood and consequences of cladding breach
- Other / Operational
  - Extended power uprates possible (8% to 17%)
  - 24 month cycle operation
  - Reduced electric demand from reactor coolant pumps
  - Reduced dose in the event of cladding breach

Lightbridge Project Plan

Milestone Schedule

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Planning efforts are in progress to identify the activities necessary to support this milestone schedule. The milestone schedule is presented here to provide an overview of the project plans, not to identify specific dates for NRC submittals.

Out of Pile Test Program

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Irradiation Test Program

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Lightbridge Fuel Demonstration Program

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Near Term Focus

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Fabrication Plans

- Utilize Framatome's US Fuel Fabrication plant in Richland, WA for process development, rods for testing, and commercial fuel for US customers

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- Process uses coextrusion, based on:
  - Lightbridge experience with U-Zr metal
  - Framatome experience with extruding cladding and metal fuel fabrication with research reactor fuel

Cast Ingot → Assemble Billet → Coextrude → Finishing

Licensing Plans – Lightbridge SAFDLs and Regulatory Framework

- Process to identify pertinent safety criteria and SAFDLs for the Lightbridge Fuel design
  - Similar to SRP Section 4.2, starting with high-level safety criteria and identifying potential failure modes/mechanisms specific to Lightbridge Fuel
  - Use established tools (FMEA, PIRT) to identify failure mechanisms, important phenomena, and knowledge gaps
    - Internal (Enfission) PIRT activities first, followed by broader participation with industry experts and NRC
    - Ensure that safety-significant phenomena are understood, test programs are sufficient, and regulatory framework is established
- Identify additional gaps in regulatory framework
- Possible submittal to establish regulatory framework to be applied to LTA and batch fuel

Licensing Plans – Leads and Fuel Qualification

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Licensing Plans – Fuel Fabrication and Transportation

- Fuel fabrication facility
  - Framatome's Richland facility will be used for Lightbridge Fuel fabrication. Specific fabrication activities performed in Richland for fabrication development and the fuel leads programs is still under evaluation.
  - Need for facility license amendment to support lead test rods depends on the LTR composition / enrichment
  - Anticipate facility licensing for LTAs being a significant schedule driver
  - Possible pre-submittal meeting in next 6-9 months when plans are better established
- Transportation
  - Composition of LTR will determine need for license amendment
  - License amendment will be necessary for shipping container to support LTA program
  - Investigating transportation options and licensing requirements for >5% enriched source material

Summary and Next Steps

- Enfission plans to demonstrate the performance and safety of Lightbridge Fuel through a series of test reactor irradiations, out-of-reactor experiments, analytical modeling, and lead test assemblies
- Purpose of meeting was to introduce the Enfission organization, key elements of the Lightbridge Fuel design, and high-level project plans
- Closing items for consideration
  - Feasibility of the proposed high-level project plan
  - NRC activities envisioned to support Lightbridge licensing efforts
- Potential near-term (12 months) meeting topics
  - Details of irradiation test program
  - Safety criteria / PIRT plans
  - Fabrication and transportation licensing plans

Abbreviations

ATR	Advanced test reactor (Idaho National Laboratory)
CHF	Critical heat flux
EU	Enriched uranium
FA	Fuel assembly
FMEA	Fuel modes and effects analysis
FCCI	Fuel-clad chemical interaction
HALEU	High assay low enriched uranium
LAR	License amendment request
LTR	Lead test rod
LTA	Lead test assembly
PIE	Post-irradiation examination
PIRT	Phenomena identification and ranking table
SAFDL	Specified acceptable fuel design limit