SOLVING ENERGY CHALLENGES
THROUGH SCIENCE

VTR Fuel Design Analysis Plan

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Note: Information regarding site location is **preliminary**. The decision for site location is determined via DOE acquisition processes that have not yet been completed.

Fuel Design Analysis Objectives

- For context, the Fuel Design Objective:

  Prepare the technical justification (Fuel Performance Design Basis) supporting our confidence in using VTR driver fuel to 10 at.% peak burnup

- Specifically for this work, the Fuel Design Analysis Objectives:

  1. *Using the best methods and codes available, quantify VTR fuel performance expectations to support startup*
     - Use BISON (and possibly LIFE-Metal) to compare predicted margin to failure in VTR fuel with those for EBR-II and FFTF fuel rods – demonstrate quantitative understanding of metal fuel life-limiting behaviors

  2. *Establish and deploy VTR fuel analysis capability that will:*
     - Support safety analyses needed during VTR operation (driver fuel and experiments)
     - Evaluate increased performance limits (e.g. burnup)
     - Evaluate VTR Mk2 driver designs

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Fuel Design Analysis Plan

- Purpose of this plan: write down all major fuel design analysis activities needed to get us from 2020 to VTR reactor startup
  - This plan covers short-, medium-, and long-term plans
  - Near-term tasks tend to be defined in more detail (as expected)
  - Given the purpose and content, this presentation isn't full of pretty pictures; my apologies in advance

- Informed by:
  - FY18 VTR Fuels R&D Plan
  - Numerous conversations with Doug Crawford and Steve Hayes
  - Some conversations with Florent Heidet, Tom Fanning, and Jordi Roglans-Ribas
  - My own thoughts, opinions, and experience from other projects including commercial nuclear industry, KAPL, and HFIR

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Fuel Design Analysis interfaces with other teams and projects

- Interactions with VTR Fuel Design Basis and Fuel Production/Fabrication
- Interactions with VTR Core Design
- Likely future interactions with VTR Nuclear Safety
  - comparing transient analyses between our areas
  - possibly look at a common benchmark

- Addition responsibility: coordinate with NEAMS and AFC as needed
  - NEAMS leads metallic fuel performance code development (BISON)
  - AFC leads technology develop efforts (e.g. MK2 driver fuel)
  - AFC, NEAMS, and perhaps ART work at INL, ANL, and LANL are all relevant to VTR FDA work
  - Coordination helps avoid rework, achieve more through complementary efforts, and ensure consistent messages

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Fuel Design Analysis Enabling Objectives

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1. Quantitatively assess predicted margin to failure (cladding breach) for VTR driver fuel steady-state operation and transient operation by comparing VTR driver fuel predictions against predictions for historical experiments where PIE data gives real data
   a) Requires establishing metallic fuel performance code versions of record
2. Support revisions to VTR Fuel Design Basis
3. Support Pu feedstock assessments (including assessing the impact of Gallium) and fuel fabrication studies
4. Benchmark metallic fuel performance codes against relevant experimental test data (EBR-II, FFTF, TREAT)
5. Risk mitigation through fuel performance S/U analysis
6. Provide VTR application feedback to metallic fuel performance code developers

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Accomplishments to Date

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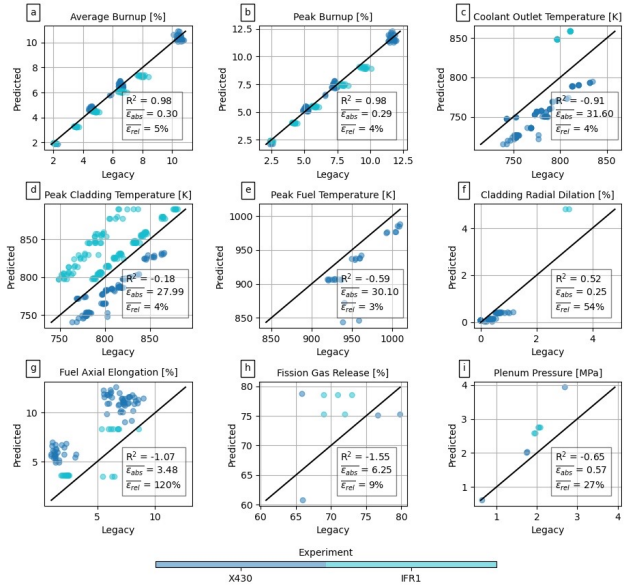
- Driver fuel analysis
  - Established BISON model of VTR reference design
  - Documented preliminary evaluations of steady-state and transient VTR driver fuel performance → identified necessary BISON improvements
  - Compared results from BISON and LIFE-METAL
- Pu feedstock assessment: U-Pu-Zr-Ga
  - Initial evaluation of potential Gallium effects
  - Examined potential effects on fuel element performance (cladding integrity, phase stability in fuel, T_{melt})
  - Interacting with INL on experimental work: identified and prioritized data needed for modeling, provided analysis results to support experimental design
- Benchmarking
  - Benchmarks created and documented for IFR-1 and X430; *JNM* paper published on IFR-1
  - Reports on Code Requirements and Benchmarking Plan are undergoing final review, will be issued soon
  - August deliverable on BISON Benchmarking Status will include additional X421 benchmark and should include broad benchmark analysis of all relevant experiments in FIPD
- Sensitivity and Uncertainty Quantification (S/U) Analysis
  - Initial S/U study of VTR driver fuel (>1000 simulations) identified strong sensitivities to coolant temperature and flow rate, recommended some approaches to minimize uncertainties in those
  - Next steps: evaluate fabrication tolerances and reasonable variations in operating conditions → identify opportunities to relax tolerances and requirements

Partial Benchmark Results



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Fuel Design Analysis Team

- This has been, and hopefully will increasingly be, a multilaboratory effort
- ORNL currently performs most FDA work
  - Jeff Powers, Jianwei Hu, Ian Greenquist, Ryan Sweet, Jake Hirschhorn
- INL's BISON team has been supporting ORNL's work through efforts including adapting BISON models for VTR us and performance improvements within BISON
  - Steve Novascone, Adam Zabriskie, Al Casagranda
- ANL has contributed LIFE-METAL analysis and review
  - Aaron Oaks, Florent Heidet

- Others from ANL and LANL could get involved if funding support is available
- Universities have been involved too, mainly University of Florida thus far

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Conclusions

- This plan is intended to be comprehensive and will be revised as appropriate, as the program continues
  - Will be soliciting more input from the fuel team
- Focus for the plan is supporting the startup case for the reference VTR fuel design using best available fuel performance codes
  - Established capability will support further developments for increasing VTR fuel burnup limits and evaluating Mk2 driver fuel design
- This is a multilaboratory effort and interacts with various other parts of the VTR project and other DOE-NE projects and programs

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Backup or optional slides

A couple key assumptions needed to be made in the FY18 R&D Plan to define scope; they remain valid

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1. **Code Development:**
   NEAMS will lead the development of a metallic fuel performance capability in BISON. As stakeholder, VTR will provide input to NEAMS activities. VTR will be ultimately responsible for validation of the code for application to VTR.

2. **Advanced Driver Fuel:**
   Advanced Fuels Campaign (AFC) will lead R&D to develop and mature an advanced driver fuel ("Mk2") for the VTR, to be qualified in VTR once reactor is operational and fuel technology is ready. As stakeholder, VTR will provide input to AFC activities including defining the required and desired characteristics of VTR Mk2 driver fuel and its expected service conditions.

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A high-level overview of activities being performed now, or planned for the future, illustrates key work: Part 1

- Driver fuel analysis: Normal Operations and Offnormal Operations (Transients)
- Support Pu feedstock assessments (including assessing the impact of Gallium) and fuel fabrication studies
  - Gallium: Assess the effects of Gallium in Pu feedstock on fuel and cladding, through activities including thermodynamics and kinetics work
- Support revisions to VTR Fuel Design Basis
- Benchmarking
  - Develop and document preliminary assessment of current metallic fuel modeling capabilities in BISON, using existing models and literature
  - Preliminary identification and prioritization of relevant historical experiments/benchmarks (EBR-II, FFTF)
  - Develop metallic fuel performance code requirements specification
  - Develop metallic fuel performance analysis benchmarking plan for VTR application
  - Significant benchmarking of BISON (specific attributes of BISON, integral performance predictions)
    - Likely an annual benchmarking status document (starting August 2021)
  - Eventual BISON and LIFE-METAL comparisons for historical experiments
  - Understand limitations of codes, catch where codes are telling us things we don’t expect and/or don’t believe

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A high-level overview of activities being performed now, or planned for the future, illustrates key work: Part 2

- Establish metallic fuel performance code versions of record
  - BISON: March 2021 version for now; update frequency currently is unspecified; likely quarterly updates at most but exceptions may happen especially early on
  - Eventually want a LIFE-METAL version of record too
- Risk mitigation through fuel performance S/U analysis of VTR driver fuel and relevant historical experiments
  - Uncertainty quantification for fuel performance models (design parameters, manufacturing tolerances, operating parameters, material models/correlations)
  - Initial sensitivity analysis using preliminary VTR driver fuel and benchmark cases (IFR-1, X430)
  - Desired outcomes:
    - Help mitigate risk factors for later generations of driver fuel
    - Identify beneficial changes or high-priority experimental measurements (separate effects tests?) that could help VTR by reducing current risks
    - Reduce risk in cost and schedule
    - Identify possible reductions in cost and schedule best estimates, through things such as increased tolerances in fuel and cladding specifications
- Supporting VTR Mk2 driver fuel development and deployment
- Support approve to operate VTR using Mk2 driver fuel, including safety basis revisions and fuel design basis revisions

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