High Performance Fuel Systems
An International Collaborative Program Supporting Commercialization of Fuel with Enhanced Accident Tolerant Characteristics

Andrew Sowder
Principal Technical Leader
Nuclear Sector

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Objectives for Development and Qualification of New Fuels

- Fuel design specifications sufficient for manufacture
- Understanding of fuel properties and behavior under irradiation to define and constrain risks:
  - adequate safety for regulatory compliance
  - adequate performance and reliability for economic operation
- Demonstration that fuel manufactured according to specifications performs in accordance with licensing basis and operator requirements in real world environment

Timely, successful development and qualification require adequate testing and characterization data.
Lessons from Advanced Zirconium Cladding Development

- Development to deployment of current Nb-based Zr alloys (e.g., ZIRLO™ and M5™) spanned 20 ± 5 years.
- Three-cycle irradiation of a lead test assembly in a commercial reactor will require 5+ years (plus PIE, etc.).
- Traditional approach to fuel qualification and licensing assumes compatibility with existing fuel and core designs:
  - Commercial reactors are not test reactors.
  - Compatibility issues with some ATF materials and designs may increase emphasis on test reactor irradiation program.
Material Characterization and Testing is an Ongoing Requirement to Maintain or Enhance Performance

- Once a new fuel or other component enters commercial service, new data needs continue to arise.
- Testing continues on Zry-2/4 after > 5 decades of service.
- New conditions (e.g., extended storage) lead to new questions.
Universal Challenges for ATF Programs

- Fundamental material characterization data needed to support development, licensing, commercialization and operation over entire product lifecycle (cradle to grave)
- Maturation of ATF for commercial deployment will continue to require substantial, sustained public sector funding
- ATF programs are, and will remain, nation-centric
- Limited resources and pressures to achieve nearer-term results may orphan promising but less mature concepts
Timing and Urgency of ATF RD&D

- Relevance to existing fleet limited by economic plant life and long deployment timeframes
- Post-Fukushima support and funding are currently high

Limited window of opportunity to benefit existing LWR fleets. New builds and SMRs are a different story.
Sustainable RD&D Path and Support Needed Beyond Near-Term Milestones

Phase 1
- Feasibility
  - Workshops
  - Feasibility studies on advanced fuel and clad concepts
    - bench-scale fabrication
    - irradiation tests
    - steam reactions
    - mechanical properties
    - furnace tests
    - modeling
  - Assessment of new concepts
    - impact on economics
    - impact on fuel cycle
    - impact on operations
    - impact on safety envelope
    - environmental impact

Industry led projects (Phase 1a)


Industry led projects (Phase 1b)


Phase 2
- Development/Qualification
  - Fuel Selection/Prioritization
  - Steady State Tests
  - Transient Irradiation Tests
  - LOCA/Furnace Tests
  - Fuel Performance Code
  - Fuel Safety Basis

Industry led projects (Phase 2)

2017 2018 2019 2020 2021 2022

LFA/LFR Ready

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Importance of Non-Fuel Core Components

- Focus of “accident tolerance” on cladding-fuel system too narrow
- Reactor performance depends on components beyond fuel and cladding:
  - BWR fuel channels
  - PWR assembly guide tubes
  - PWR control rods and BWR control blades
  - Other core internals
- Opportunity to gain in-core experience with new materials in less challenging applications
Many Players, Many Opportunities – But Can All Data Needs Be Met Individually?

- National RD&D programs
- Industrial teams and consortia
- Existing fuel testing resources and programs
- International ATF-oriented forums:
  - OECD/NEA Expert Group on Accident Tolerant Fuels for Light Water Reactors (EGATFL)
  - IAEA Coordinated Research Program: Analysis of Options and Experimental Examination of Accident Tolerant Fuels for Water Cooled Reactors (ACTOF)

Sustained, collaborative material characterization and fuel testing could leverage national and industrial efforts to fill RD&D gaps.
Current International Activities in ATF

- Australia
- Austria
- Belgium
- Canada
- Czech Republic
- Denmark
- Finland
- France
- Germany
- Greece
- Hungary
- Iceland
- Ireland
- Italy
- Japan
- Luxembourg
- Mexico
- Netherlands
- Norway
- Poland
- Portugal
- Republic of Korea
- Russian Federation
- Slovak Republic
- Slovenia
- Spain
- Sweden
- Switzerland
- Turkey
- United Kingdom
- United States

Current development or testing activity
Collaboration, analysis or proposal activity

China

observer participation
## Summary of ATF R&D Activities: Cladding

![Image](https://via.placeholder.com/576x6)

### Courtesy of S. Bragg-Sitton

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<td><strong>Russia</strong></td>
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<td><strong>Sweden</strong></td>
<td><strong>see U.S. DOE-sponsored work led by Westinghouse</strong></td>
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<td><strong>United Kingdom</strong></td>
<td><strong>U.K. university participation in U.S. University-based research</strong></td>
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*Non-fuel rod accident tolerant SiC/SiC activities:
- BWR channel box – U.S., Japan
- AT control rod (ATCR) – Japan

**Research groups in the U.K. and Australia also participate in U.S. University-led research.
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EPRI Perspective

- Public sector support required for “de-risking” ATF RD&D
- Early and sustained industry engagement is also essential
- **No single entity or group will succeed alone**
- Timely, successful development and qualification require adequate testing, irradiation, and characterization data
- EPRI faces a decision whether to launch an international collaborative ATF-related program in 2017
  - based on time-tested collaboration model
  - to coordinate and **sustain** common-need, pre-competitive testing
  - encompassing core components beyond fuel-cladding

**Benefits from ATF arise with widespread commercial adoption. RD&D must be performed with vendors and utilities close at hand.**
EPRI Proposal

- High Performance Fuel Systems (HPFS) collaborative program to support:
  - characterization and testing of new, advanced materials and concepts for LWR fuels and fuel systems
  - commercially relevant, viable concepts that balance safety, economics and performance

NORMAL OPERATIONS
  - Safety
  - Economy
  - Performance

ACCIDENT CONDITIONS
  - Safety
  - Performance
Building on Proven Collaborative Models

*Irradiation-assisted stress corrosion cracking

- Modeled after other successful EPRI-led programs:
  - Cooperative IASCC* Research (CIR) program
  - Nuclear Fuel Industry Research (NFIR) program
  - Advanced Radiation Resistant Materials (ARRM) program
  - Long Term Operations (LTO) program


**ARRM (2012 – 2022)**

Develop new non-fuel core materials

**HPFS**

Develop new fuel & non-fuel core materials for enhanced accident tolerance

**NFIR**

Phase I - 1982

Understand and improve performance of Zry – UO₂ fuel system

Phase VII – 2015+
High Performance Fuel Systems Collaborative

COORDINATED EVALUATION
Review and evaluate prior and ongoing R&D

PLANNING
Identify technical gaps and prioritize testing plans

EXECUTION
Execute on testing plans and integrate results

High Performance Fuel Systems (HPFS) Program

Future

Current Status in Individual Countries

Government Programs

Fuel Suppliers

R&D Labs and Universities

Regulators

Utilities
EPRI Proposal: High Performance Fuel Systems Collaborative

High Performance Fuel Systems (HPFS) Program

Use results from OECD/NEA as starting point

PLANNING
Identify technical gaps and prioritize testing plans

EXECUTION
Execute on testing plans and integrate results

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Key Partners for Collaboration

- Government agencies and national laboratories
- Fuel suppliers, vendors
- Utility champions
- International organizations
- Academic institutions
- Regulators

Because of low technology maturity, government agencies and national laboratories will likely represent the primary source of funding initially.
Why EPRI?

- Independent, non-profit center for public interest energy and environmental research

- Collaborative resource for the electricity sector
  - 450+ participants in more than 40 countries
  - International funding of nearly 25% of EPRI’s research, development and demonstrations (40% nuclear)
  - EPRI members account for 100% of nuclear generation in the United States
  - EPRI programs engage ~ 80% of nuclear operators worldwide

EPRI combines successful collaborative R&D experience with unparalleled access to nuclear operators worldwide.
Strawman - Pillars of EPRI HPFS Program

- Multi-year collaborative RD&D program focused on pre-commercial, common need testing and characterization
- Characterize common classes of materials:
  - coatings on fuel cladding and other core components
  - ceramic/composite materials for fuel cladding and other non-fuel components (SiC)
  - advanced steels
  - refractory metals
- Focus on fuel and fuel-related core components
  - performance of non-fuel core components also drives accident progression and mitigation and recovery options
  - non-fuel applications provide path of least resistance to commercial in-core testing
- Wide-range of relevant primary system conditions
  - normal ops and transients to severe accidents
  - primary coolant chemistry (PWR, BWR, VVER)
EPRI Near-Term Plan for HPFS Program

2012 - 15
I. Global engagement

Present
II. Socialization, review viability for EPRI go / no-go decision

2016
III. Partner engagement (individually and via workshops) to establish interest, resources, support and scope

2017
IV. Rollout as EPRI supplemental program
EPRI Near-Term Plan for HPFS Program

- Extensive, early engagement with USDOE and labs, vendors, utilities and other key international partners
- Fall 2016: NEA EGATFL State of Technology report complete

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Together...Shaping the Future of Electricity