SAND2012-5162C

Sodium Fast Reactor Fuels and Materials: Research Needs

Chicago, Illinois
June 26th, 2012

Matthew Denman (Speaker) – Sandia National Laboratories

Leon Walters, Panel Chair – Advanced Reactor Concepts
John Lambert, Ken Natesan, Art Wright, Abdellatif Yacout – Argonne National Laboratory
Steven Hayes, Douglas Porter – Idaho National Laboratory
Larry Ott – Oak Ridge National Laboratory
Frank Garner – Radiation Effects Consulting

SAND2012-XXXX C

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Outline

Project Overview	• The Fuels and Materials (F&M) Report was the last of five related SFR gap reports
Panel Selection	• What processes were used?
Ranking Process	• How were relative research needs determined?
Key Findings	• What future work is necessary in F&M to support an SFR safety case?

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Project Overview
Sodium Fast Reactor (SFR) Research Plan

What
- Identifies the current state of Safety-Related Gaps for the SFR
- Prioritizes gap closures

Why
- Uncertainties exist regarding DOEs capability to support a SFR license application

How
- Panels were formed in 5 topical areas to elicit the current state-of-SFR-licenseability

Who
- Organized by: Denman (SNL), LaChance (SNL), Sofu (ANL), Flanagan (ORNL), Wigeland (INL), and Bari (BNL)
- 42 experts from the DOE lab complex, academia, industry and international bodies

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Project Overview

Planning

Initial Gap Identification and Rankings (~3 years)

Final Evaluation (~1 year)

What topical areas are vital to SFR Licensing?

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Panel Selection

Requirements

- Attempt to ensure that all sub-topics were represented by at least one panelist
- Ensure representation from a diverse cross-section of stakeholders

Organization

- Formulate short-list of qualified chairs with expertise within SFR F&M (Leon Walters was ultimately selected)
- Leverage the planning group's knowledge with L. Walter's contacts to select a multidisciplinary expert panel
- Select a time when all panelists could meet at Argonne for three days!

Approach

- Semi-structured discussion of sub-topical areas lead by the appropriate Subject Matter Expert (SME)
- SME assigned initial rankings and then group debated the accuracy of the rankings
- Once initial rankings were determined, SMEs reviewed all rankings for consistency
- SMEs provide summary write-ups for their topical areas

Ranking Process

Regulatory Significance

High (H)

- The phenomenon of interest can directly lead to a material failure
- The regulatory body will require a high degree of confidence in the experimental database, materials knowledge or modeling techniques.

Medium (M)

- The phenomenon is of secondary importance to understanding overall material performance and failure.
- The regulatory body will desire information about the phenomenon.

Low (L)

- Understanding the phenomenon of interest is not instrumental to predicting material performance

State of Knowledge

High (H)

- A physics- or correlation-based model that adequately represents the phenomenon over the parameter space of interest is available.
- A database exists adequate to validate relevant models or to make an assessment.

Medium (M)

- A candidate model or correlation is available that addresses most of the phenomenon over a considerable portion of the parameter space.
- Data are available but are not necessarily complete or of high fidelity, allowing only moderately reliable assessments.

Low (L)

- No model exists, or model applicability is uncertain or speculative.
- No database exists; assessments cannot be made reliably.

Topics Examined In Detail

Topics Chosen for Analysis*

- Fresh metal and oxide fuel at 10 at%, 20 at%, and greater than 20 at% burnup.
- Metal and oxide fuel with minor actinide additions at 10 at%, 20 at%, and greater than 20 at% burnup.
- Metal and oxide fuel with carry-over of fission products from reprocessing at 10 at%, 20 at% and greater than 20 at% burnup.
- Life-limiting phenomena and properties for 316 cladding.
- Life-limiting phenomena and properties for HT-9 cladding.
- Life-limiting phenomena and properties for advanced materials (e.g., 9Cr-1Mo or ferritic-martensitic steels).
- Life-limiting phenomena and properties for 316 ducts.
- Life-limiting phenomena and properties for HT-9 ducts.
- Macroscopic thermal physical properties—metal UZr/UPuZr.
- Macroscopic thermal physical properties—UO2/MOX

Example Ranking Tables

Table 1. Potential Life-Limiting Phenomena for Fresh Fuel

Fuel Phenomena	Regulatory Concern, Metal/Oxide	Metal, L.T. 10at%	Metal, L.T. 20at%	Metal, G.T. 20at%	Oxide, L.T. 10at%	Oxide, L.T. 20at%	Oxide, G.T. 20at%
Axial Growth	L / (N/A)	H	M	L	N/A	N/A	N/A
Fuel Swelling and FCMI	H /M	H	M	L	H	M	L
Gas Release	H / H	H	H	L	H	H	H
Fuel Constituent Redistribution	M/ M	H	M	L	H	M	L
FCCI	H / M	H	M	L	H	M	L
Fuel/Coolant Compatibility	L / H	H	H	H	H	L	L

Note: Experiment 496, a low smear density metal fuel test currently being irradiated, will increase our understanding of low smear density metal fuel

Table 5. Phenomena and Properties for HT9 Cladding

Cladding Phenomena / Properties	Regulatory Concern	Low dpa (<100) / Low P.C.T.* (550-560°C)	Low dpa / High P.C.T. (~630°C)	High dpa (~200) / Low P.C.T.	High dpa / High P.C.T.
Creep Rate	H	H	M	H	L
Swelling Rate	M	H	M	H	L
Fracture Toughness Properties	M	H	M	H	L
Yield Strength	M	H	M	H	L
Carbon Mass Transport	L	N/A	N/A	N/A	N/A
FCCI**	M	H	M	H	M

*P.C.T. – Peak Cladding Temperature, ** Only applicable to metal fuel, ***N/A- Not Applicable
Note: Fabrication is not readily available, must be demonstrated to be consistent with historical HT9 database through mechanical and radiation testing.

*Balance of Plant materials expert was not available, thus previous analysis was leveraged: K. Nateson, M. Li, S. Majumdar, R. Nanstad, T.-L. Sham, "Preliminary Assessment of code Qualification for ABR Structural Materials," ANL-AFCI-244, September 2008.

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Key Safety Related Gaps

Gaps were identified in a variety of subject areas

Two gaps will be focused on as part of this talk:

- SFR Fuels and Materials Knowledge Preservation
- Fuel Performance Code and Document Training

Gap ID	Name of Gap Topical Areas	Importance to Safety Within Category	State of Knowledge
FM01	High Burnup Fuel Characterization	H	M
FM02	Fission Product Carryover Fuel Characterization	H	L
FM03	MA Carryover Fuel Characterization	H	L
FM04	Advanced Cladding and Duct Fabrication, HT-9, 9Cr-1Mo, ODS	H	M
FM05	Advanced Cladding and Duct Material Properties	H	M
FM06	Duct/Bundle Performance Experience	H	L
FM07	Structural Material Issues, Rotating Plug, IHX, EM Pump	M	L
FM08	Brayton (S/CO_2) Materials Issues	H	L
FM09	SFR Fuels and Materials Knowledge Base Preservation	H	L
FM10	Fuel Performance Code Documentation and Training Issues	H	L

SFR Fuels and Materials Knowledge Preservation

Both the steady-state and off-normal irradiation database would be sufficient to support a conservative design.

- The existing data must be retrievable and in a form that is acceptable to the licensing body.
- Fabrication experience for fuel, cladding, and ducts must also be retrieved to provide assurance that the core materials could be replicated such that the existing database is applicable. It must be appreciated that few, if any, vendors of these materials exist.

An effort should be made to:

- Inventory the existing fuel performance database,
- Collect the hard copy information and store it in approved storage locations, and
- Transfer this information to an electronic database that can be readily queried.
- **Exactly the same effort should be carried out for the fuel fabrication processes.**

A comprehensive knowledge management program is needed to not only record but analyze the FFTF, TREAT, and EBR-II data.

- Much of these data are not easily decipherable and will need experts from the corresponding facility to properly understood

Fuel Performance Code and Document Training

Virtually all the gaps were related to the fact that there has been little attention given to fuel performance code development for the last two decades.

- Most of the code routines are empirically based as opposed to mechanistically based and thus are useful primarily for interpolation when adequately validated with existing data.

In addition, few people are adept in exercising the codes with documentation less than adequate for the training of new users.

Fuel performance codes such as the LIFE codes need to be maintained in terms of documentation, personnel, and funding.

- If this gap is not closed soon, no person in the DOE complex will have experience with these codes.

Summary

A multi-year effort has been finished which examined gaps which must be closed to defend the SFR's safety case

Two overarching gaps were apparent throughout the F&M gap analysis discussions. These gaps were:

- The need for a test SFR such as EBR-II or FFTF to enhance the existing knowledge base.
- Uncertainty in the preservation state of the existing knowledge base.

It is extremely important to secure the existing database

- Without EBR-II, FFTF, and TREAT the information cannot be duplicated.
- Even in the event that such facilities become available in the future, duplication of these irradiations would be expensive and time consuming.

Thank You for Your Time.

This work is a product of a project supported by the US Department of Energy under work package number A-11SN040201. The views presented here are those of the authors and do not necessarily represent the views of the US Department of Energy.

This work was overseen and managed by Jeffrey LaChance (Sandia National Laboratories), who provided guidance on the approach taken, attended the expert elicitation panel meeting, and provided useful input during the report preparation. Recognition is also given to Tyrell Arment (MIT) for his assistance during the expert elicitation process.