GAIN: Innovative Materials Research Workshop

June 15, 2022

OKLO

Aurora

FAST FISSION BY OKLO

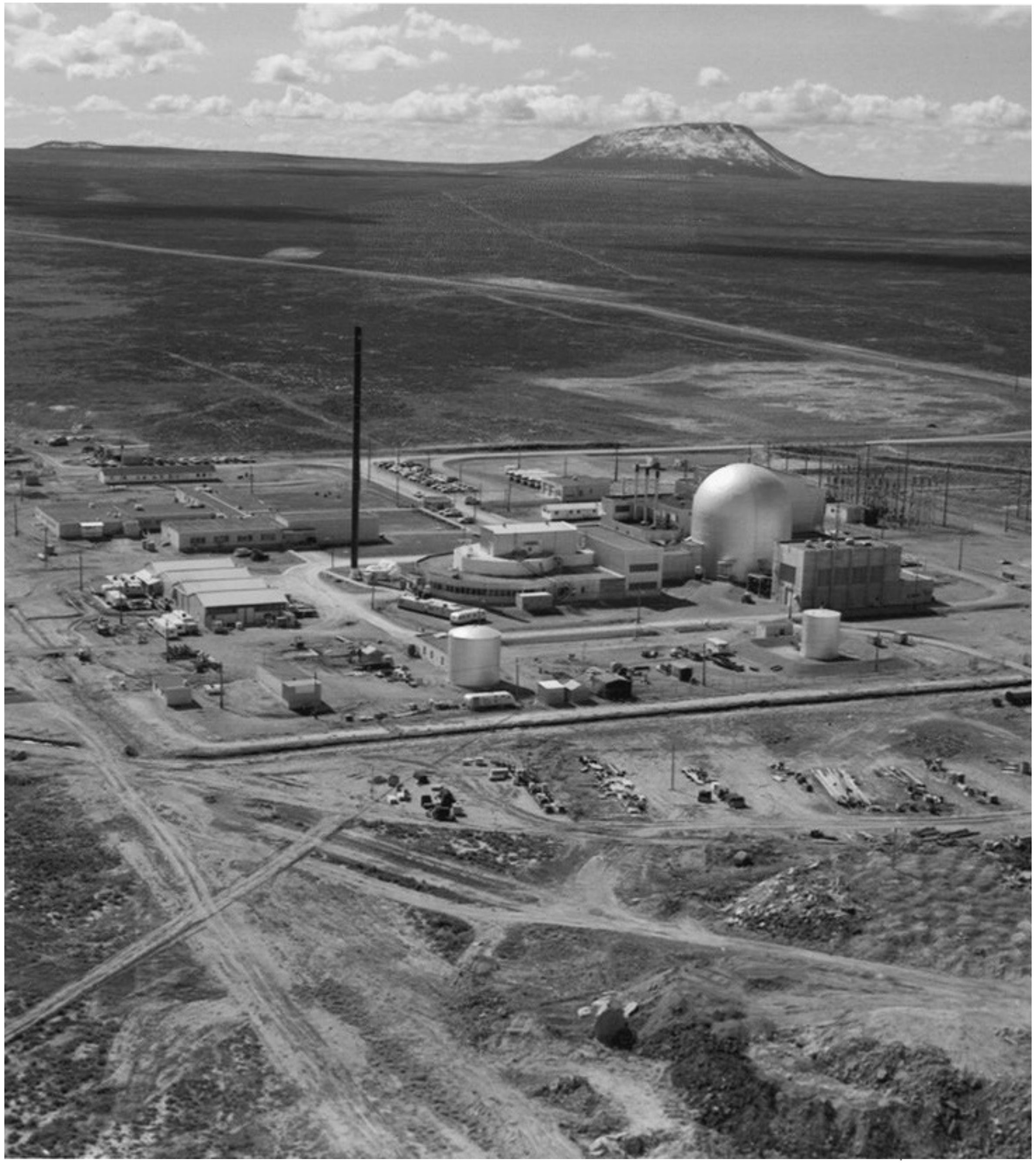
OKLO

Making reactors people want

- **Affordable and reliable, 24/7 carbon-free power**
- **Flexible siting**
- **Minimal water resources required**
- **Inherently simple and robust**
- **Designed for performance**

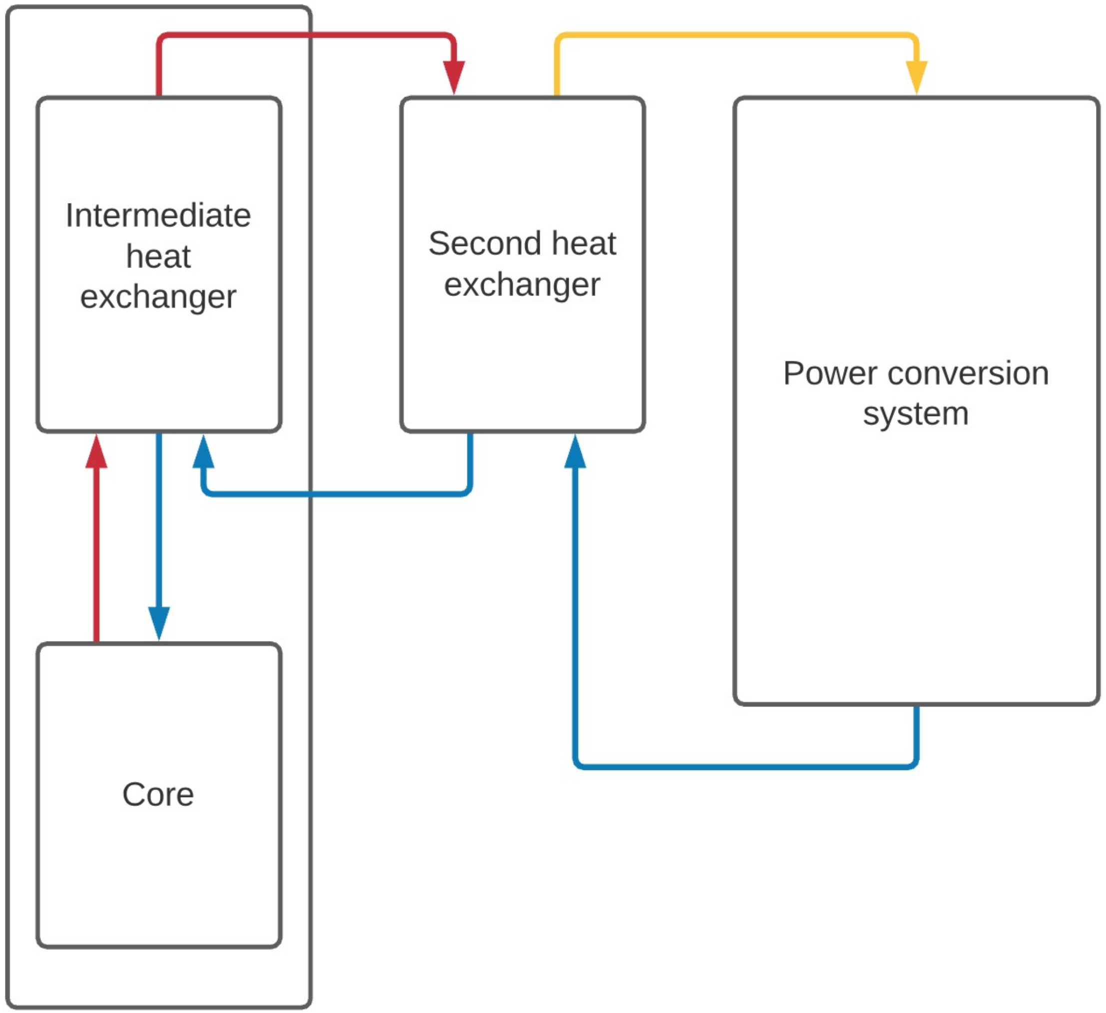
A RICH HISTORY

The Aurora builds on the legacy of the **Experimental Breeder Reactor II**, a sodium-cooled fast reactor with onsite recycling of used fuel. EBR-II operated from 1964-1994, demonstrating inherent safety characteristics and the ability to recycle fuel.



How it works

- Heat is generated by fission and transferred to liquid metal coolant
- Heat is then carried to the power conversion system
- The power conversion system converts heat to electricity, and can also deliver heat directly



DESIGN PARAMETERS

Electric capacity	**1 to 15 MWe**
Thermal capacity	**4 to 50 MWt**
Temp. of usable heat	**500-550 C**
Capacity factor	**>90%**
Licensed operating life	**20+ years**
Frequency of refueling	**10-20 years**
Land usage	**<1 acre**

Larger designs in development as well

CLADDING & CORE MATERIALS

Cladding & Core Materials

1-5 years	5-10 Years	10+ Years

Near Term

- Core materials manufactured from existing alloys such as ferritic/martensitic and austenitic stainless steel or legacy super alloys
- **Challenges**
  - Limited Supply Chain Capacity, Capability, and Desire

Intermediate Term

- Existing alloys manufactured with FCCI barriers
- Incremental improvements of existing alloys
- Commercial availability of new alloys (e.g., refractory metal- based alloys)
- **Challenges**
  - Performance Data
  - Supply Chain Development

Long Term

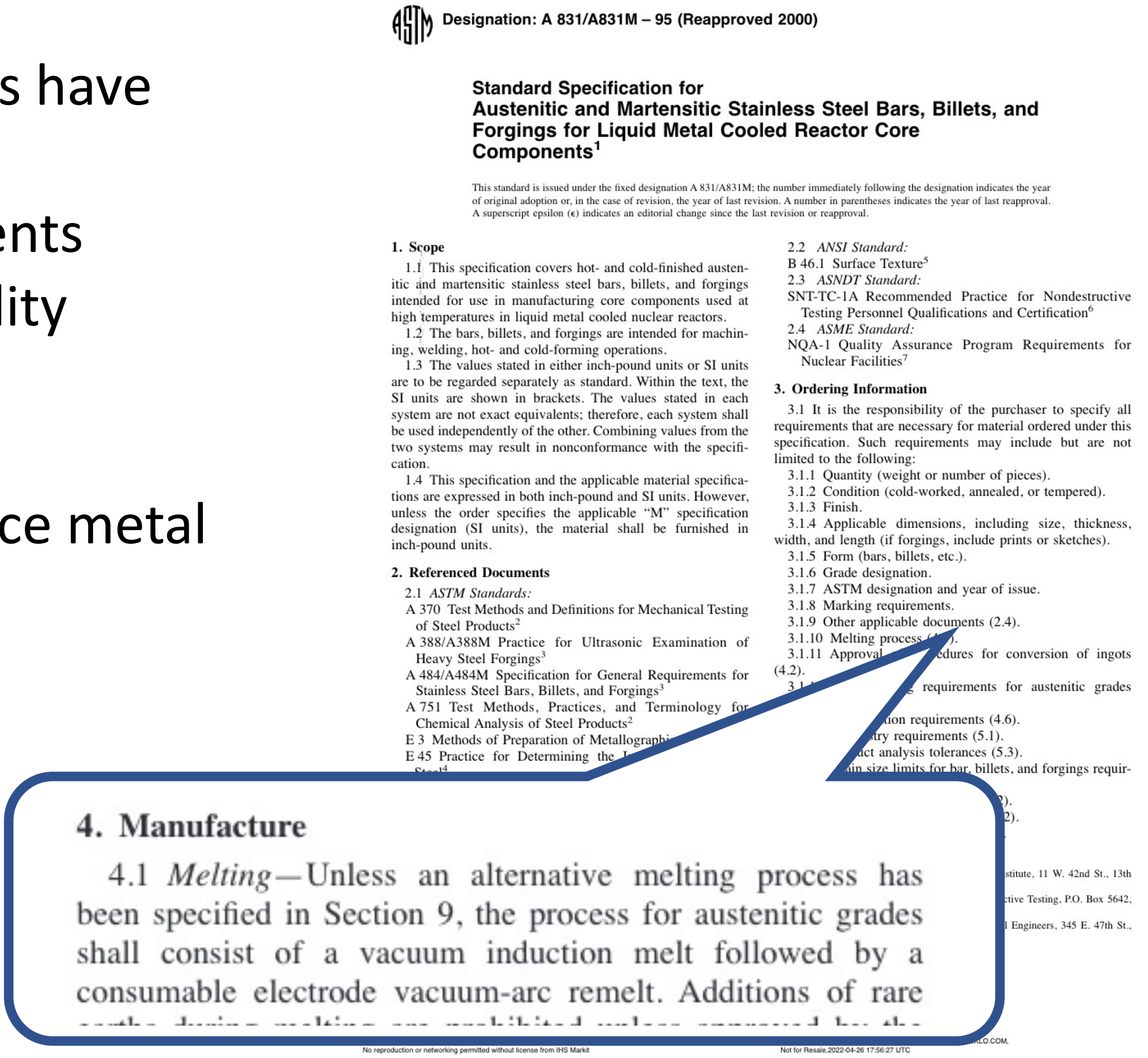
- Oxide dispersion Strengthened (ODS) Alloys
- New manufacturing methods
- Advanced fuel forms
- **Challenges**
- Performance Data
- Limited to no existing supply chain

CLADDING & CORE MATERIALS (NEAR TERM)

- Designers with near term deployments have gravitated towards “available” alloys
  - Leverage data from past experiments
  - Tap existing manufacturing capability

- **Challenge**
  - US Supply Chain capacity to produce metal meeting typical “nuclear grade” requirements is limited

- **Opportunity**
  - Refine legacy requirements
  - Develop new suppliers



Designation: A 831/A831M – 95 (Reapproved 2000)

Standard Specification for Austenitic and Martensitic Stainless Steel Bars, Billets, and Forgings for Liquid Metal Cooled Reactor Core Components[1]

This standard is issued under the fixed designation A 831/A831M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers hot- and cold-finished austenitic and martensitic stainless steel bars, billets, and forgings intended for use in manufacturing core components used at high temperatures in liquid metal cooled nuclear reactors.

1.2 The bars, billets, and forgings are intended for machining, welding, hot- and cold-forming operations.

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.4 This specification and the applicable material specifications are expressed in both inch-pound and SI units. However, unless the order specifies the applicable “M” specification designation (SI units), the material shall be furnished in inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[2]

A 388/A388M Practice for Ultrasonic Examination of Heavy Steel Forgings[3]

A 484/A484M Specification for General Requirements for Stainless Steel Bars, Billets, and Forgings[3]

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products[2]

E 3 Methods of Preparation of Metallographi

E 45 Practice for Determining the

2.2 *ANSI Standard:*

B 46.1 Surface Texture[5]

2.3 *ASNDT Standard:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualifications and Certification[6]

2.4 *ASME Standard:*

NQA-1 Quality Assurance Program Requirements for Nuclear Facilities[7]

3. Ordering Information

3.1 It is the responsibility of the purchaser to specify all requirements that are necessary for material ordered under this specification. Such requirements may include but are not limited to the following:

3.1.1 Quantity (weight or number of pieces).

3.1.2 Condition (cold-worked, annealed, or tempered).

3.1.3 Finish.

3.1.4 Applicable dimensions, including size, thickness, width, and length (if forgings, include prints or sketches).

3.1.5 Form (bars, billets, etc.).

3.1.6 Grade designation.

3.1.7 ASTM designation and year of issue.

3.1.8 Marking requirements.

3.1.9 Other applicable documents (2.4).

3.1.10 Melting process

3.1.11 Approval edures for conversion of ingots (4.2).

requirements for austenitic grades

ion requirements (4.6).

try requirements (5.1).

ct analysis tolerances (5.3).

in size limits for bar, billets, and forgings requir-

stitute, 11 W. 42nd St., 13th

ctive Testing, P.O. Box 5642,

Engineers, 345 E. 47th St.,

4. Manufacture

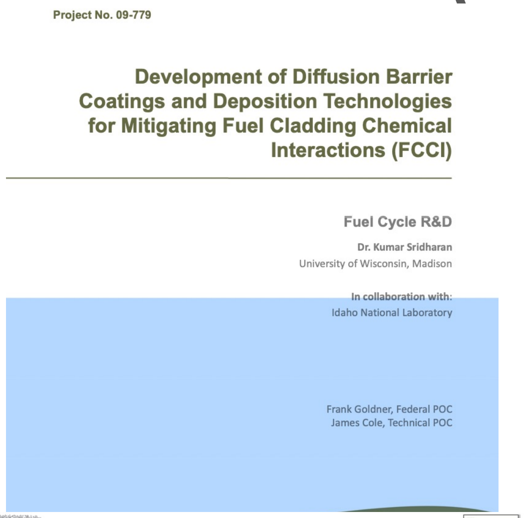
4.1 *Melting*—Unless an alternative melting process has been specified in Section 9, the process for austenitic grades shall consist of a vacuum induction melt followed by a consumable electrode vacuum-arc remelt. Additions of rare

Cladding & Core Materials (Intermediate)

- Improvement of existing alloys using metallurgical fundamentals
  - Austenitic Alloys
  - Impact of Manufacturing Variability on Properties
  - Product Form Variations

- Development of a Commercial Source for New Alloys
  - Refractory alloys (e.g., vanadium)

- Fabrication of cladding from existing alloys with FCCI barrier for SFRs



Project No. 09-779

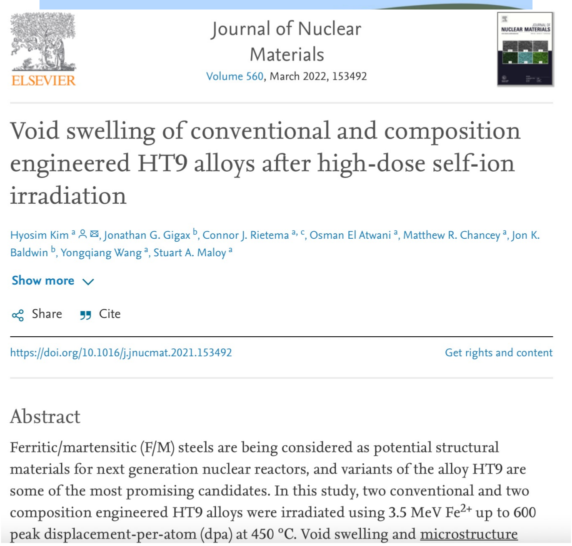
Development of Diffusion Barrier Coatings and Deposition Technologies for Mitigating Fuel Cladding Chemical Interactions (FCCI)

Fuel Cycle R&D

Dr. Kumar Sridharan
University of Wisconsin, Madison

In collaboration with:
Idaho National Laboratory

Frank Goldner, Federal POC
James Cole, Technical POC



Journal of Nuclear Materials
Volume 560, March 2022, 153492

ELSEVIER

Void swelling of conventional and composition engineered HT9 alloys after high-dose self-ion irradiation

Hyosim Kim [a], Jonathan G. Gigax [b], Connor J. Rietema [a, c], Osman El Atwani [a], Matthew R. Chancey [a], Jon K. Baldwin [b], Yongqiang Wang [a], Stuart A. Maloy [a]

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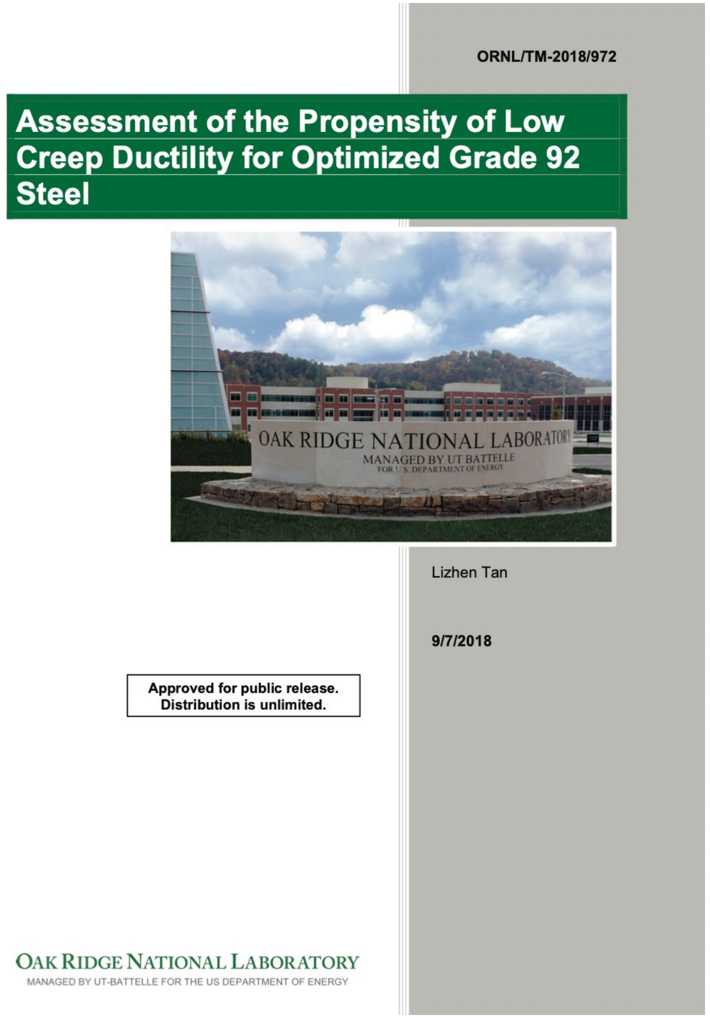
Abstract

Ferritic/martensitic (F/M) steels are being considered as potential structural materials for next generation nuclear reactors, and variants of the alloy HT9 are some of the most promising candidates. In this study, two conventional and two composition engineered HT9 alloys were irradiated using 3.5 MeV Fe^{2+} up to 600 peak displacement-per-atom (dpa) at 450 °C. Void swelling and microstructure



ORNL/TM-2018/972

Assessment of the Propensity of Low Creep Ductility for Optimized Grade 92 Steel

Lizhen Tan

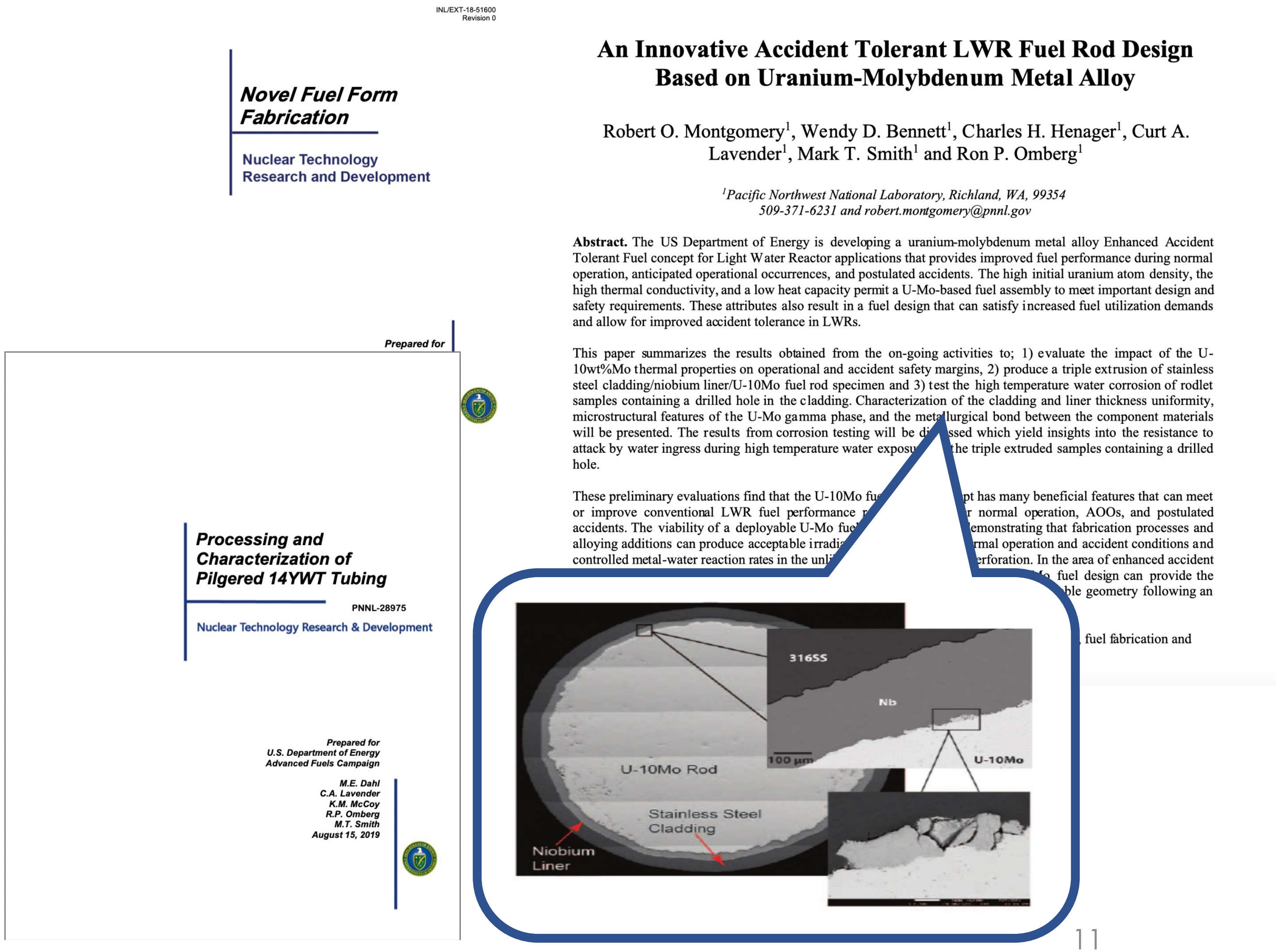
9/7/2018

Approved for public release. Distribution is unlimited.

Oak Ridge National Laboratory
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

Cladding & Core Materials (Long Term)

- Oxide Dispersion Strengthened Alloys
  - Commercial source capable of producing ODS quantities at scale
- New Manufacturing Methods
  - Co-fabrication of cladding + wire wrap (SFRs)
  - Additive Manufacturing
- Advanced Fuel Forms



INL/EXT-18-51600
Revision 0

Novel Fuel Form Fabrication

Nuclear Technology Research and Development

Prepared for

Processing and Characterization of Pilgered 14YWT Tubing

PNNL-28975

Nuclear Technology Research & Development

Prepared for
U.S. Department of Energy
Advanced Fuels Campaign

M.E. Dahl
C.A. Lavender
K.M. McCoy
R.P. Omberg
M.T. Smith
August 15, 2019

An Innovative Accident Tolerant LWR Fuel Rod Design Based on Uranium-Molybdenum Metal Alloy

Robert O. Montgomery[1], Wendy D. Bennett[1], Charles H. Henager[1], Curt A. Lavender[1], Mark T. Smith[1] and Ron P. Omberg[1]

[1]*Pacific Northwest National Laboratory, Richland, WA, 99354*
509-371-6231 and robert.montgomery@pnnl.gov

Abstract. The US Department of Energy is developing a uranium-molybdenum metal alloy Enhanced Accident Tolerant Fuel concept for Light Water Reactor applications that provides improved fuel performance during normal operation, anticipated operational occurrences, and postulated accidents. The high initial uranium atom density, the high thermal conductivity, and a low heat capacity permit a U-Mo-based fuel assembly to meet important design and safety requirements. These attributes also result in a fuel design that can satisfy increased fuel utilization demands and allow for improved accident tolerance in LWRs.

This paper summarizes the results obtained from the on-going activities to; 1) evaluate the impact of the U-10wt%Mo thermal properties on operational and accident safety margins, 2) produce a triple extrusion of stainless steel cladding/niobium liner/U-10Mo fuel rod specimen and 3) test the high temperature water corrosion of rodlet samples containing a drilled hole in the cladding. Characterization of the cladding and liner thickness uniformity, microstructural features of the U-Mo gamma phase, and the metallurgical bond between the component materials will be presented. The results from corrosion testing will be di... ssed which yield insights into the resistance to attack by water ingress during high temperature water exposu... the triple extruded samples containing a drilled hole.

These preliminary evaluations find that the U-10Mo fu... pt has many beneficial features that can meet or improve conventional LWR fuel performance ... r normal operation, AOOs, and postulated accidents. The viability of a deployable U-Mo fue... emonstrating that fabrication processes and alloying additions can produce acceptable irradi... rmal operation and accident conditions and controlled metal-water reaction rates in the unli... erforation. In the area of enhanced accident ... fuel design can provide the ... ble geometry following an ... fuel fabrication and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