Microreactor Licensing

NRC Policy and Technical Readiness

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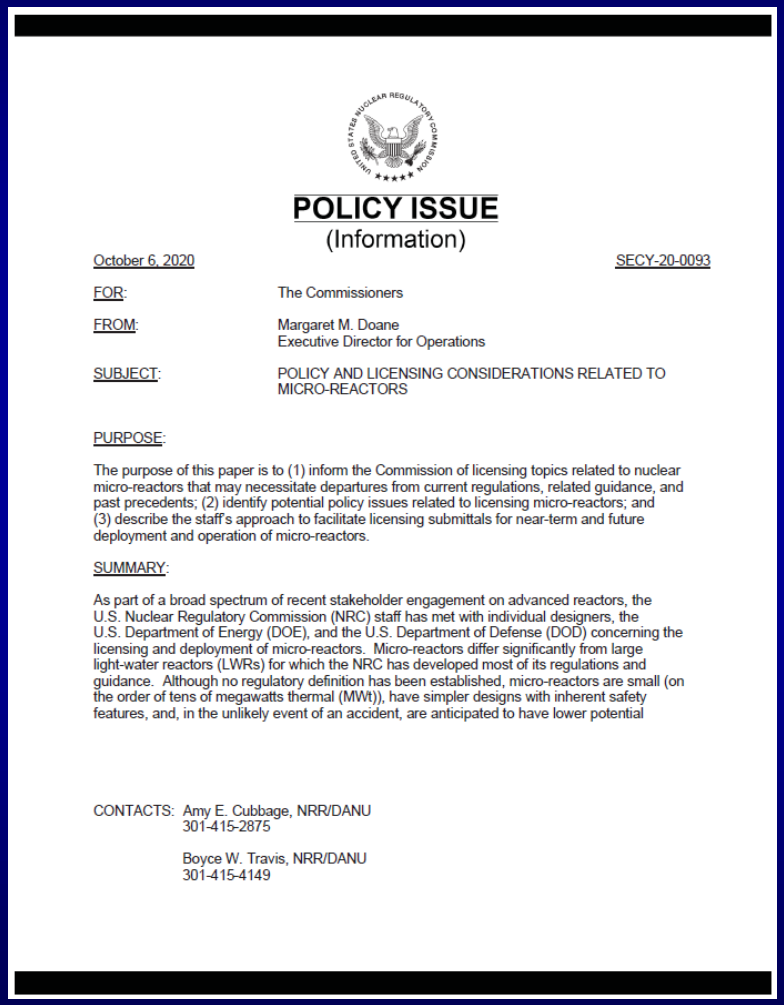
United States Nuclear Regulatory Commission

GAIN Microreactor Stakeholders Workshop
May 12, 2021

Introduction

- The NRC has been preparing for review and licensing of a wide variety of advanced reactors.
- Microreactors have received significant attention due to several unique features.
  - *May be transportable or located in remote locations.*
  - *Expected to have increased safety margins and reliance on simplified, passive, and inherent safety features.*
  - *May use heat pipes or natural processes for heat removal.*
- Both policy and technical capabilities addressed as part of NRC readiness.

Policy and Licensing Considerations



POLICY ISSUE
(Information)

October 6, 2020 SECY-20-0093

FOR: The Commissioners

FROM: Margaret M. Doane
Executive Director for Operations

SUBJECT: POLICY AND LICENSING CONSIDERATIONS RELATED TO MICRO-REACTORS

PURPOSE:

The purpose of this paper is to (1) inform the Commission of licensing topics related to nuclear micro-reactors that may necessitate departures from current regulations, related guidance, and past precedents; (2) identify potential policy issues related to licensing micro-reactors; and (3) describe the staff's approach to facilitate licensing submittals for near-term and future deployment and operation of micro-reactors.

SUMMARY:

As part of a broad spectrum of recent stakeholder engagement on advanced reactors, the U.S. Nuclear Regulatory Commission (NRC) staff has met with individual designers, the U.S. Department of Energy (DOE), and the U.S. Department of Defense (DOD) concerning the licensing and deployment of micro-reactors. Micro-reactors differ significantly from large light-water reactors (LWRs) for which the NRC has developed most of its regulations and guidance. Although no regulatory definition has been established, micro-reactors are small (on the order of tens of megawatts thermal (MWt)), have simpler designs with inherent safety features, and, in the unlikely event of an accident, are anticipated to have lower potential

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- SECY-20-0093, "Policy and Licensing Considerations Related to Micro-Reactors"
  - Current rules
  - Stakeholder perspectives
  - Position/Actions
- **Items are being updated continuously**
  - https://www.nrc.gov/reactors/new-reactors/advanced.html

Activity on Policy/Licensing Items

Item	Activity
Security	Rulemaking – 10 CFR 73 (limited scope)
Emergency Planning	Rulemaking – 10 CFR 50.160
Staffing, Training, Qualifications*	Staff plans to use NUREG-1791 to evaluate exemptions
Autonomous and Remote Operation*	Contract with BNL to develop a method for scaling scope and depth of human factors engineering
Regulatory Oversight	Developing an oversight program appropriate for microreactors
Aircraft Impact Assessment	Rulemaking - 10 CFR 53
Annual Fees	Rulemaking – changes to 10 CFR 171
Manufacturing and Transportation	Rulemaking – 10 CFR 53
Population and Siting	Awaiting Commission decision on SECY-20-0045
Environmental	Rulemaking – changes to 10 CFR 51 (rulemaking package to include Generic Environmental Impact Statement)

* These items are discussed further in "Risk-Informed and Performance-Based Human-System Considerations for Advanced Reactors," (ADAMS Accession No. ML21069A003). This work does not address remote operation.

Safety Testing Requirements

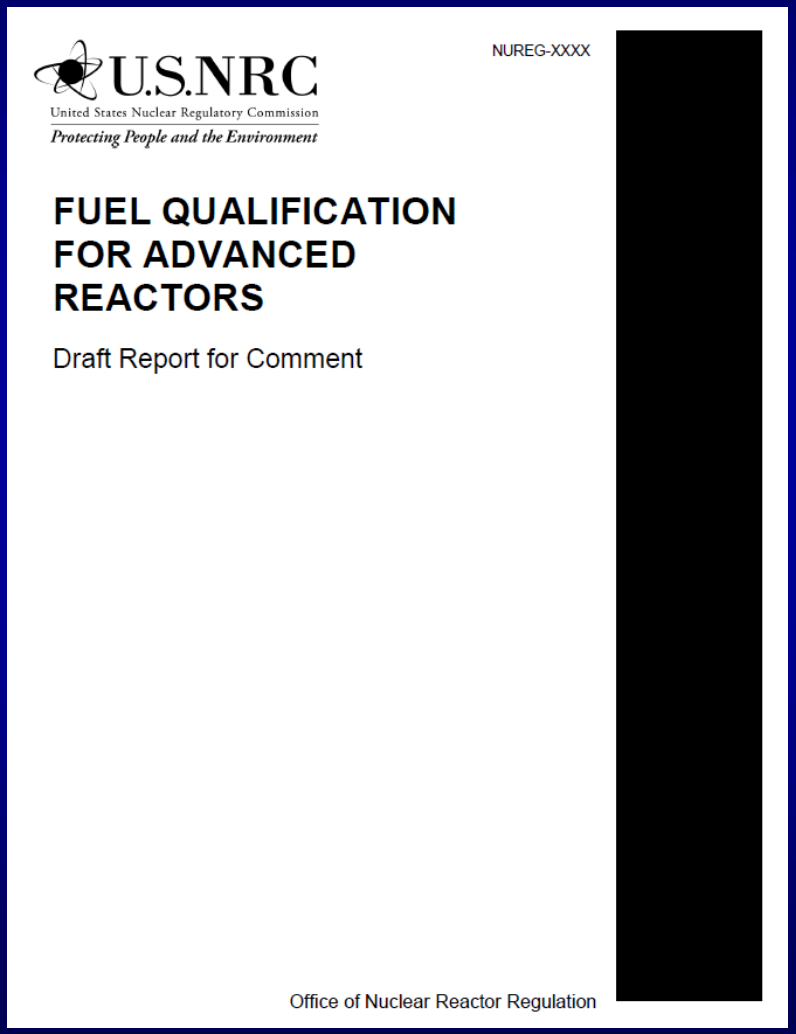
10 CFR 50.43(e) Applications for a design certification, combined license, manufacturing license, operating license or standard design approval that propose nuclear reactor designs which differ significantly from light-water reactor designs that were licensed before 1997. Or use simplified, inherent, passive, or other innovative means to accomplish their safety functions will be approved only if:

- (1)(i) The performance of each safety feature of the design has been demonstrated through either analysis, appropriate test programs, experience, or a combination thereof;
- (ii) Interdependent effects among the safety features of the design are acceptable, as demonstrated by analysis, appropriate test programs, experience, or a combination thereof; and
- (iii) Sufficient data exist on the safety features of the design to assess the analytical tools used for safety analyses over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences, including equilibrium core conditions; or

Safety Testing Requirements

- (2) There has been acceptable testing of a prototype plant over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences, including equilibrium core conditions. If a prototype plant is used to comply with the testing requirements, then the NRC may impose additional requirements on siting, safety features, or operational conditions for the prototype plant to protect the public and the plant staff from the possible consequences of accidents during the testing period.

Fuel Qualification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Protecting People and the Environment

NUREG-XXXX

FUEL QUALIFICATION FOR ADVANCED REACTORS

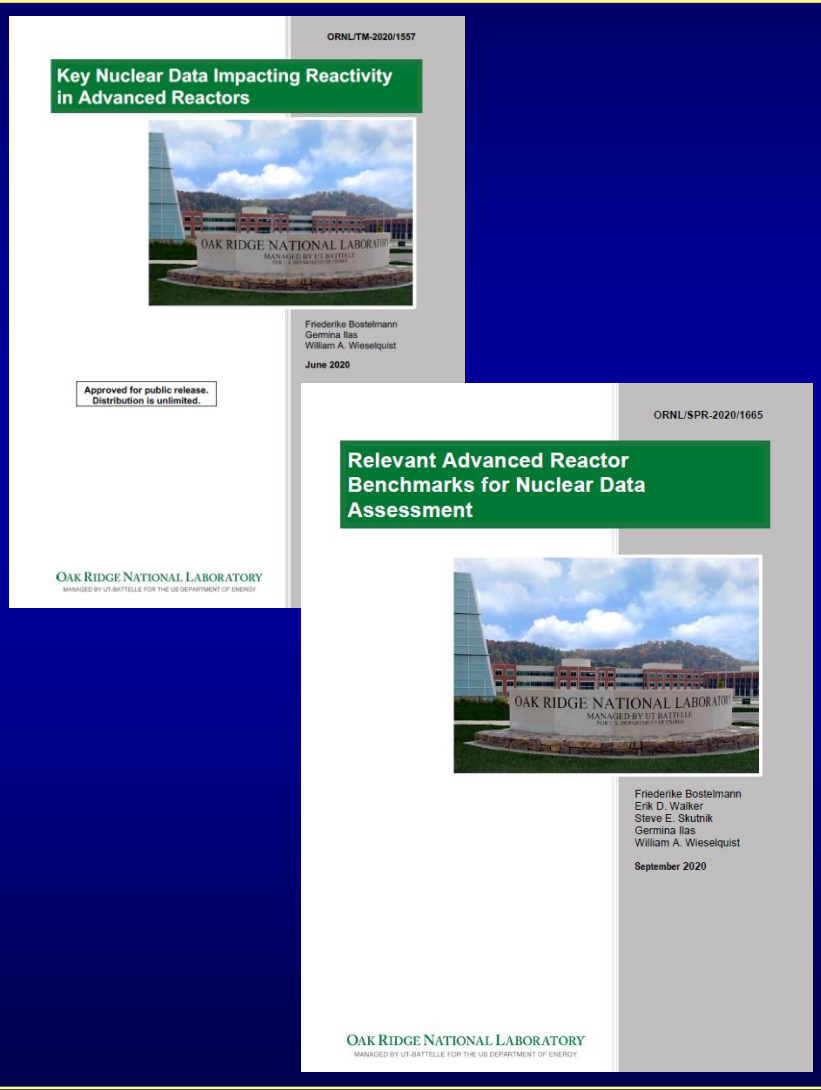
Draft Report for Comment

[redacted]

Office of Nuclear Reactor Regulation

- NUREG to be issued for public comment in late May/June
  - Draft white paper presented at October 2020 Stakeholder meeting
  - ACRS meeting in Feb. 21
  - Similar report approved by OECD/NEA/CNRA
- Contract with INL for a generic evaluation of metal fuel

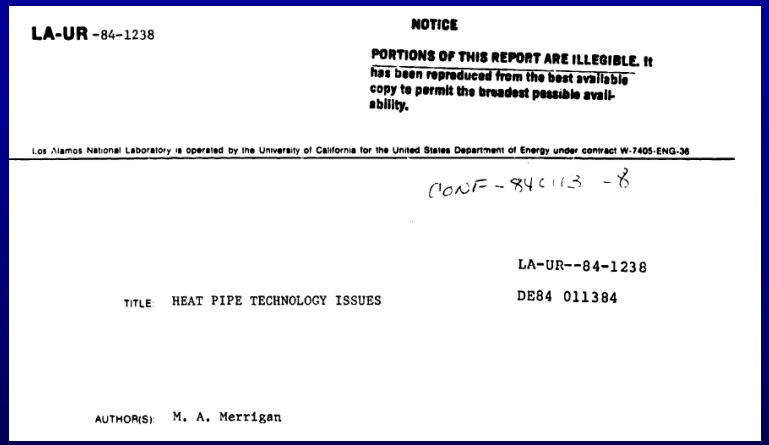
Nuclear Data



- Contract with ORNL to investigate nuclear data for advanced reactors
  - Data gaps and uncertainties
  - Impact on figures of merit:
    - Reactivity balance
    - Reactivity coefficients
    - Shutdown margin
    - Power distribution

Possible Information Needs for Microreactors

- Heat Pipes:
  - In-pile instrumentation to detect conditions of degraded core cooling for a spectrum of heat pipe failure/degradation modes
  - Heat pipe thermal-bond design and performance
  - Heat pipe performance under transient and accident conditions



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TITLE: HEAT PIPE TECHNOLOGY ISSUES

AUTHOR(S): M. A. Merrigan

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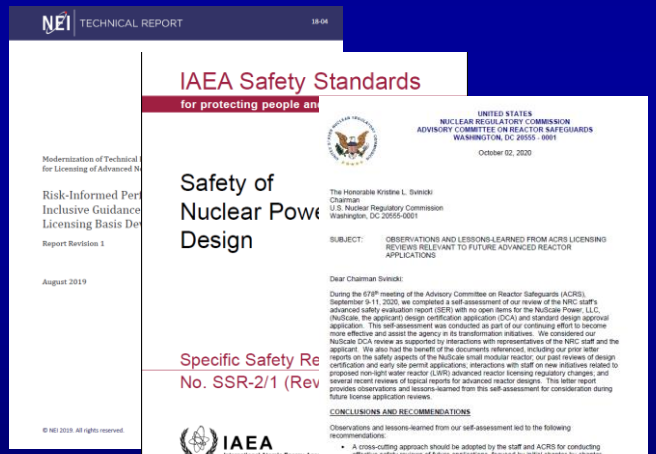
Possible Information Needs for Microreactors

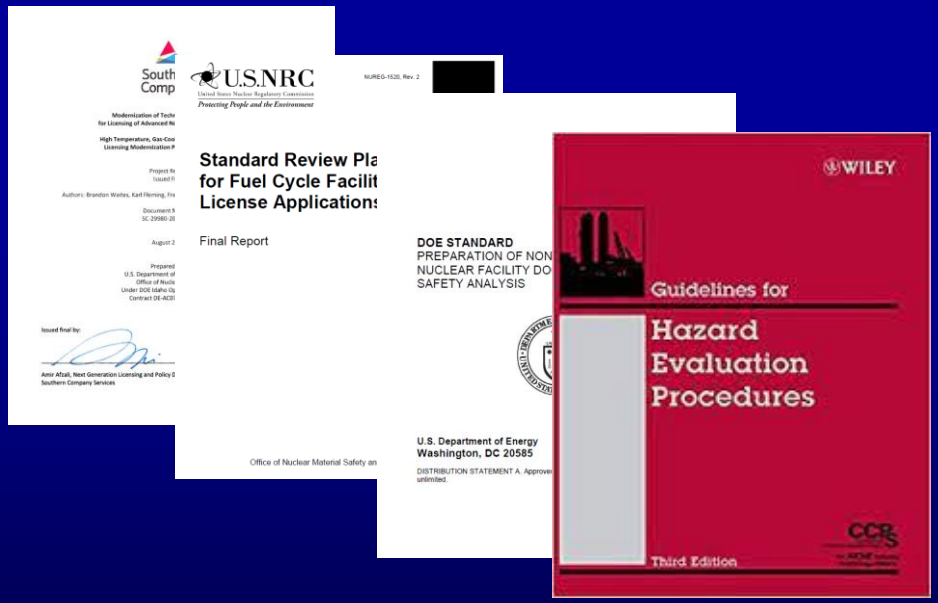
- Initiating event/hazard analysis:
  - How do we know that we considered everything (or at least everything important to safety)?
  - What process did you use?



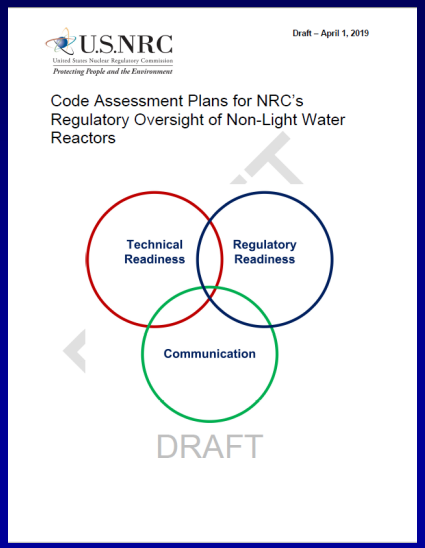
NEI 18-04

SSR-2/1

ACRS Letter
(ML20267A655)



NRC Code Development Reports



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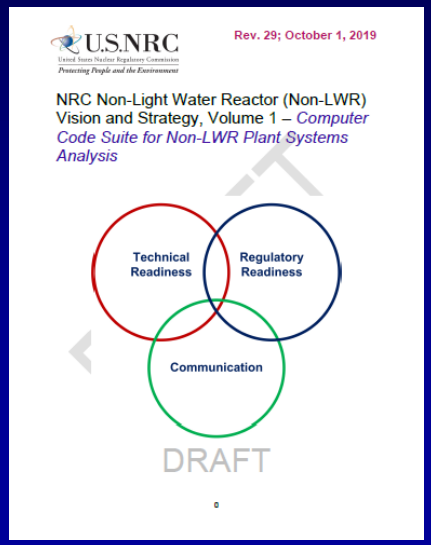
Introduction



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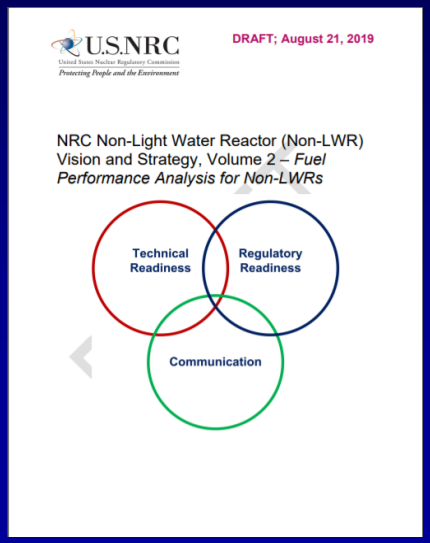
Volume 1



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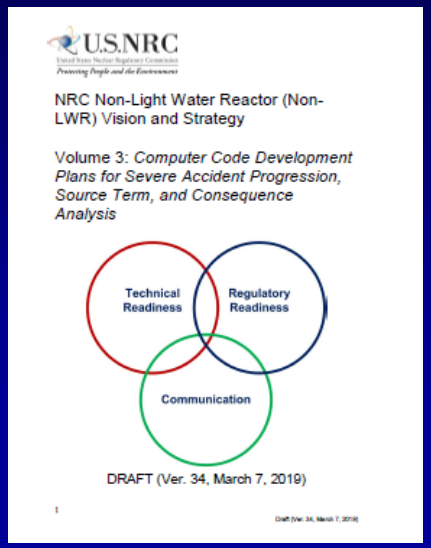
Volume 2



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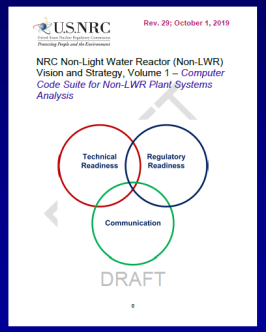
Volume 3

Volume 4 = Licensing and Siting Dose Assessment
Volume 5 = Fuel Cycle Topics

Recently Completed

These Volumes outline the specific analytical tools to enable independent analysis of non-LWRs, technical "gaps" in capabilities, V&V needs. Gaps in experimental data is currently being identified.

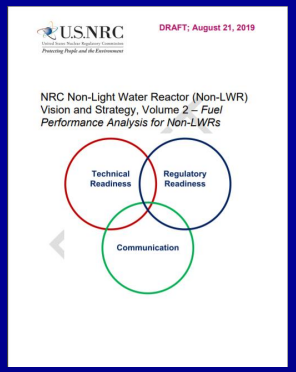
Capabilities in Volumes 1-3



Volume 1

- Are safety functions/systems adequate?
- Are the operating limits acceptable?
- Are the ARDC satisfied?
- How does the machine work?

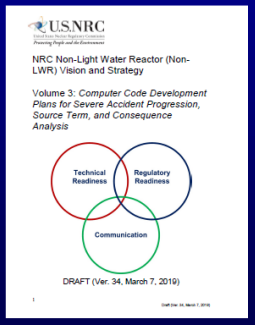
Initial Conditions
Material Properties
Failure Mechanisms



Volume 2

Initial Conditions
Material Properties
Failure Mechanisms

Volume 3



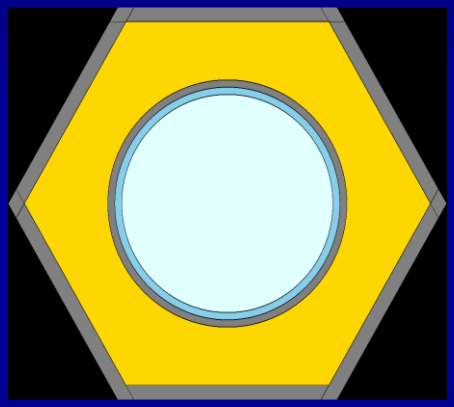
- What is the fission product inventory?
- What is the Source Term?
- Where can the fission products go?

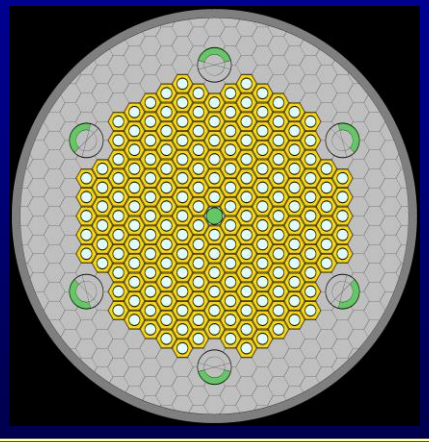
Reference Plant Models

- The set of reports identified analytical codes and some of the known “gaps”.
- An important next step in code readiness is development of a “reference plant” model which will:
  - *Contain many / most features expected in a design*
  - *Exercise code(s) to be used in analysis*
  - *Provide early identification of technical issues*
- Significant progress made in the areas of systems analysis (Vol. 1), fuel performance (Vol. 2) and severe accident/source term analysis (Vol. 3).

NRC's Microreactor "Reference Model"

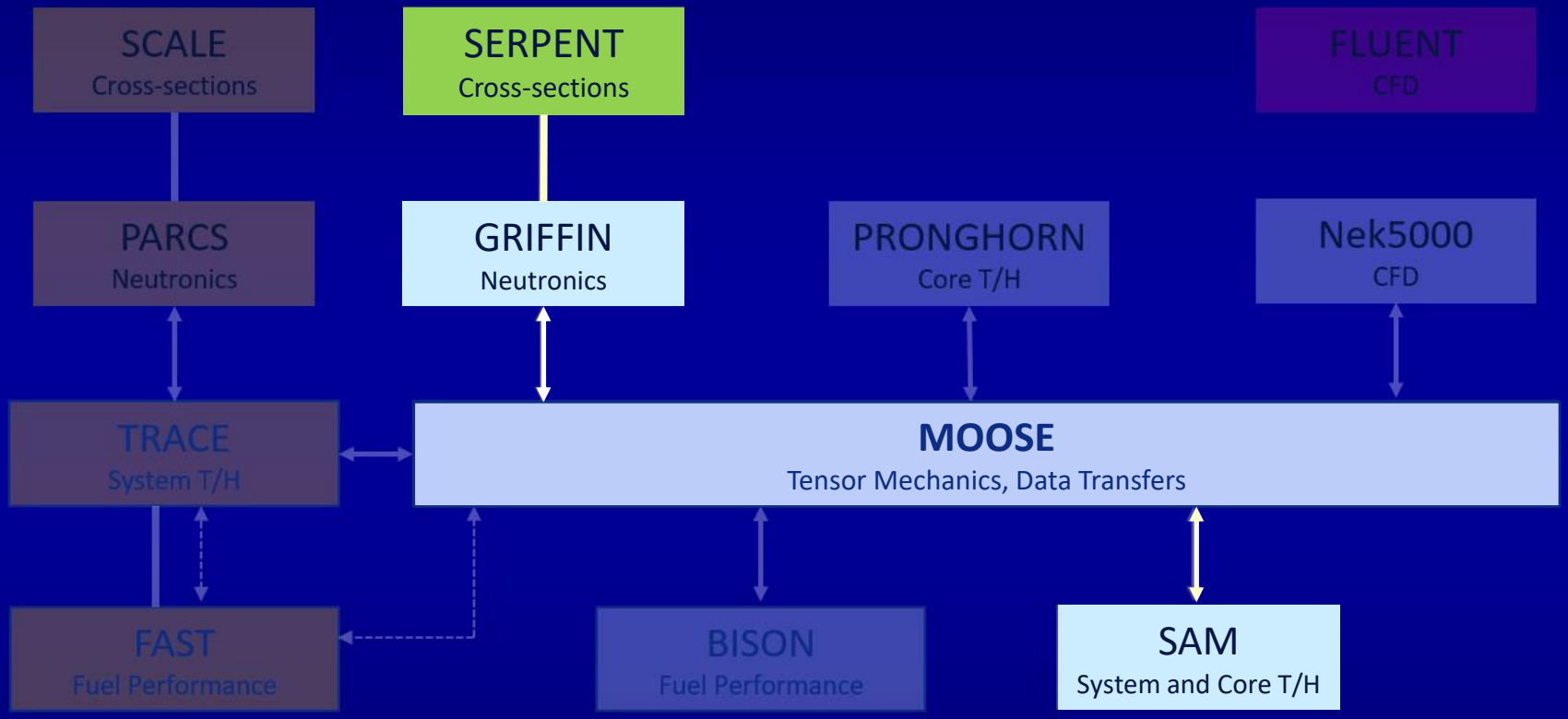
- Based on the "Design A" microreactor described by Sterbentz et al [INL/EXT-17-43212, Rev. 1] , with several simplifications.





Comprehensive Reactor Analysis Bundle

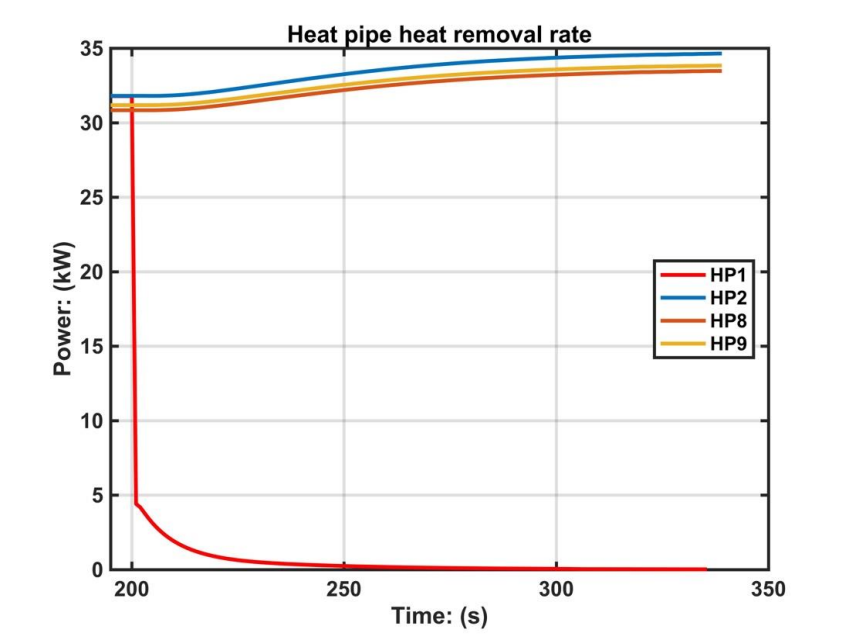
BlueCRAB - MicroReactor



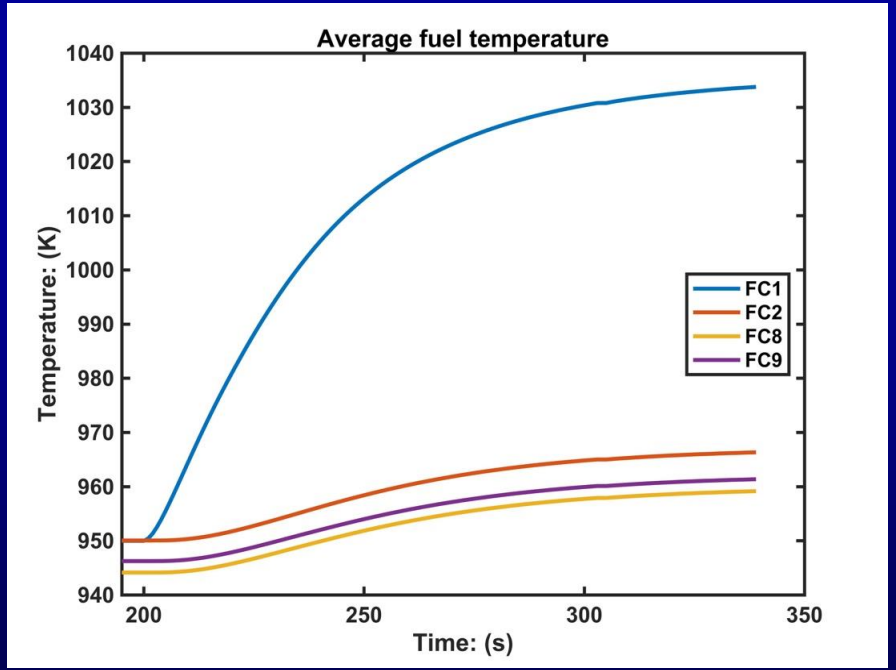
NRC Code | Int'l Code | Commercial | DOE Code

Planned Coupling | Completed Coupling | Input/BC Data

Single Heat Pipe Failure

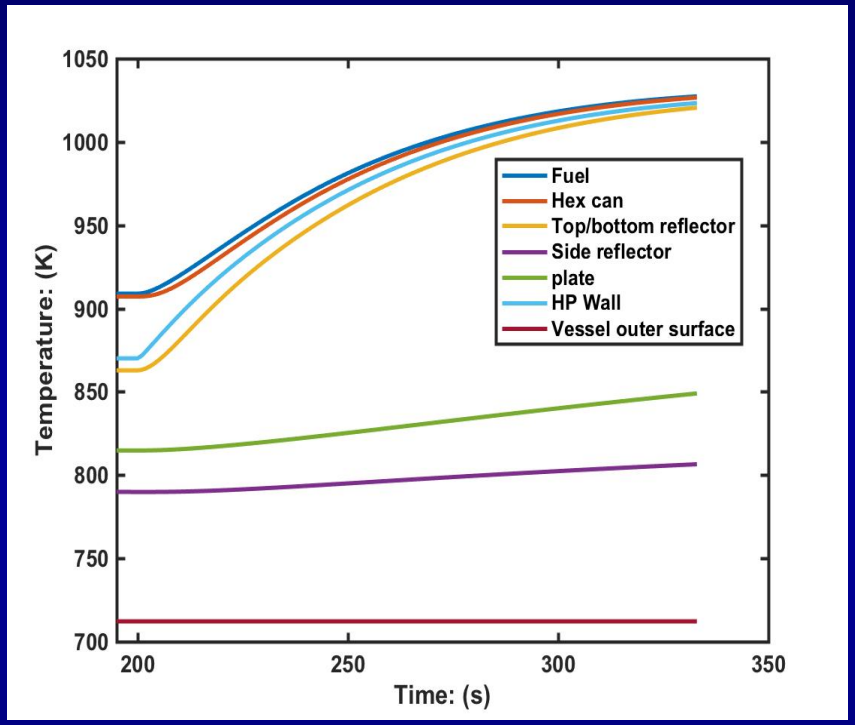


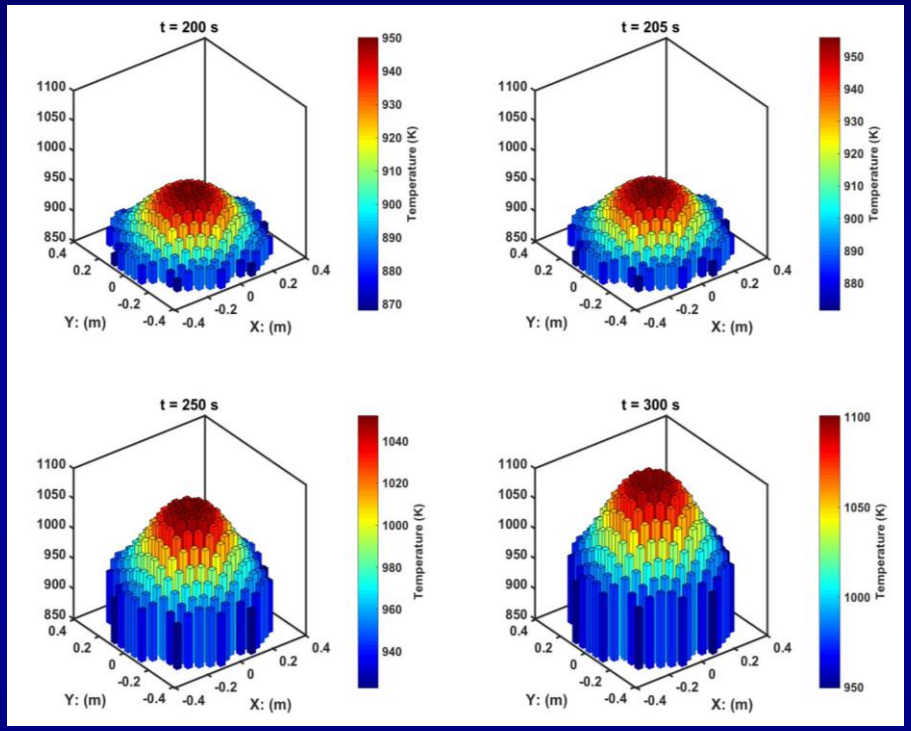
Fuel temperatures increase near failed HP and surrounding elements.



Heat removal by failed HP drops quickly, but increases in surrounding HPs.

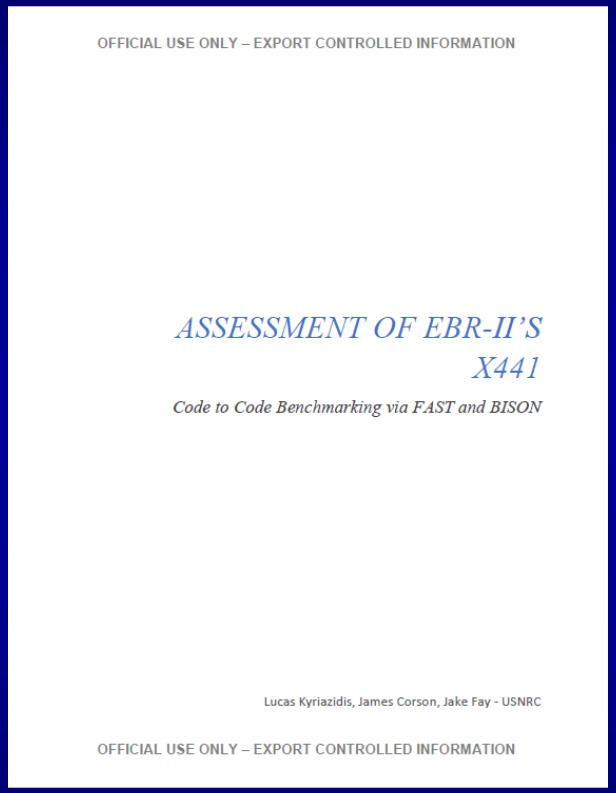
Loss of Heat Sink





Heat removal by HPs stops and fuel temperatures increase. Strong negative reactivity due to core expansion results in decrease in core power.

Fuel Performance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ASSESSMENT OF EBR-II'S X441

Code to Code Benchmarking via FAST and BISON

Lucas Kyriazidis, James Corson, Jake Fay - USNRC

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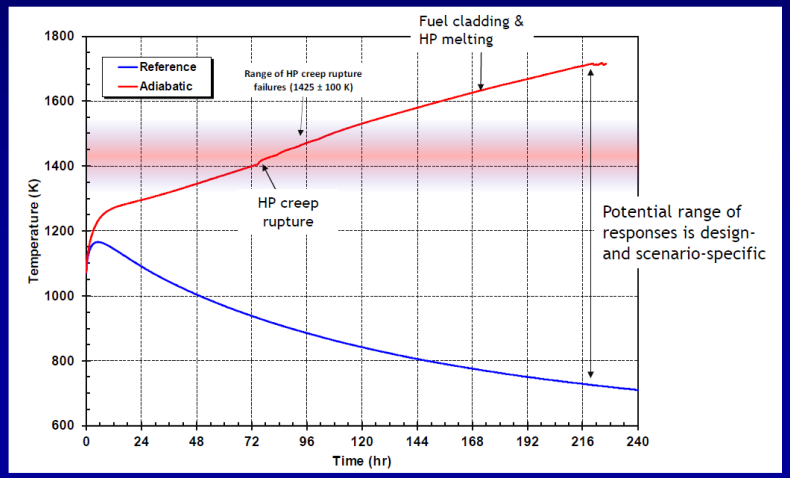
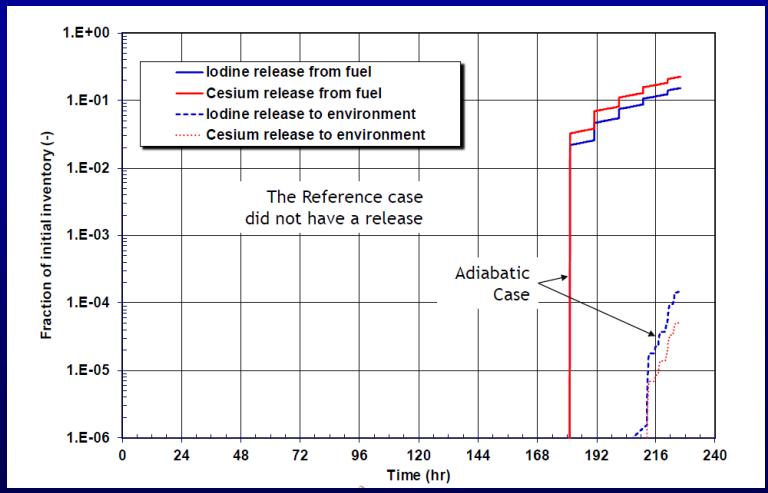
ADAMS Accession Number ML21076A416

- NRC completed assessment of X441 experiment (EBR-II) with both FAST and BISON
  - Added to existing assessment cases for the codes
- Assessment showed codes have capabilities needed to model metallic fuel
  - Improved fission gas release and fuel swelling models are being added to both codes to reduce conservatisms in modeling, especially for low burnup fuels
- Assessment improved staff knowledge of metallic fuel behavior and existing computational capabilities.

Severe Accident / Source Term

- INL “Design A” models developed for SCALE and MELCOR.
- Models used to demonstrate capability to calculate fuel temperatures for design basis and beyond design basis scenarios.
- Iodine and cesium releases estimated (for BDBE).





Current Technical Status

- The NRC is continuing to develop reference plant models and prepare analysis codes for independent analysis of microreactors.
  - BlueCRAB system of codes has been demonstrated as capable of microreactor simulation and providing “details” on the thermal, mechanical and neutronic response.
  - Fuel performance codes tested for metallic fuel.
  - MELCOR and SCALE used to simulate fission product release for a microreactor for “adiabatic” scenario.
- NRC is now capable of performing independent analysis of microreactors anticipated for upcoming reviews.

Technical Issues

- Validation. Data to validate capability of code(s) to simulate coupled thermal – mechanical expansion for microreactor geometries of interest.
  - SPHERE
  - MAGNET
  - MARVEL
  - KRUSTY

  } Valuable !

- Heat pipe performance; steady-state and transient.
- Secondary system modeling
- Exterior environment (confinement & heat removal)


Questions?