Higher Burnup Workshop

Public Meeting

Accident Tolerant Fuel

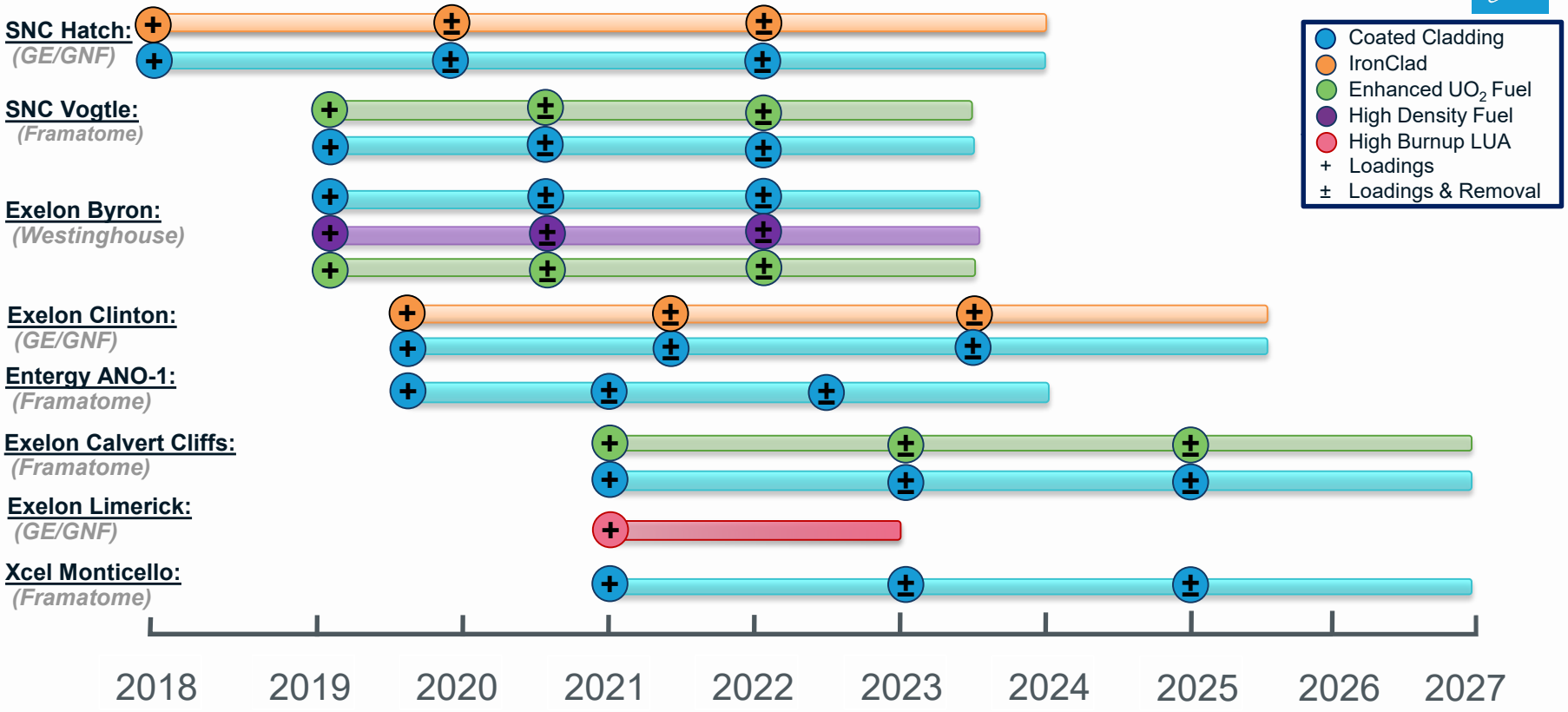
June 10th, 2021

NUCLEAR ENERGY INSTITUTE

Industry ATF Adoption Plans

BEN HOLTZMAN, NEI

Key U.S. ATF Fuel Milestones



CRAFT/ESCP

ROB DAUM, EPRI
HATICE AKKURT, EPRI
BILL GASSMANN, EXELON
DAN WACHS, INL

Collaborative Research on Advanced Fuel Technologies for LWRs (CRAFT)

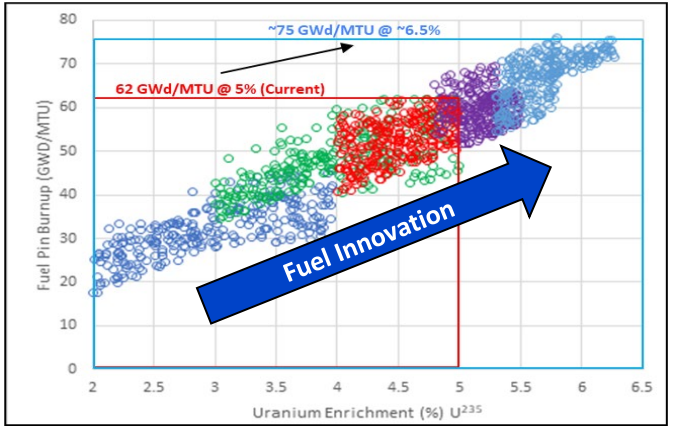
Rob Daum
Sr. Technical Executive, EPRI

Public Meeting – Higher Burnup Workshop II
U.S. Nuclear Regulatory Commission
June 10, 2021

Understanding the Benefits and Risks of LWR Advanced Fuel Technologies

- Safety, performance, and economic analyses of LWR advanced fuel technologies across the entire fuel cycle
  - Accident Tolerant Fuel (ATF)
  - **Higher Burnup**
  - Increased Enrichment

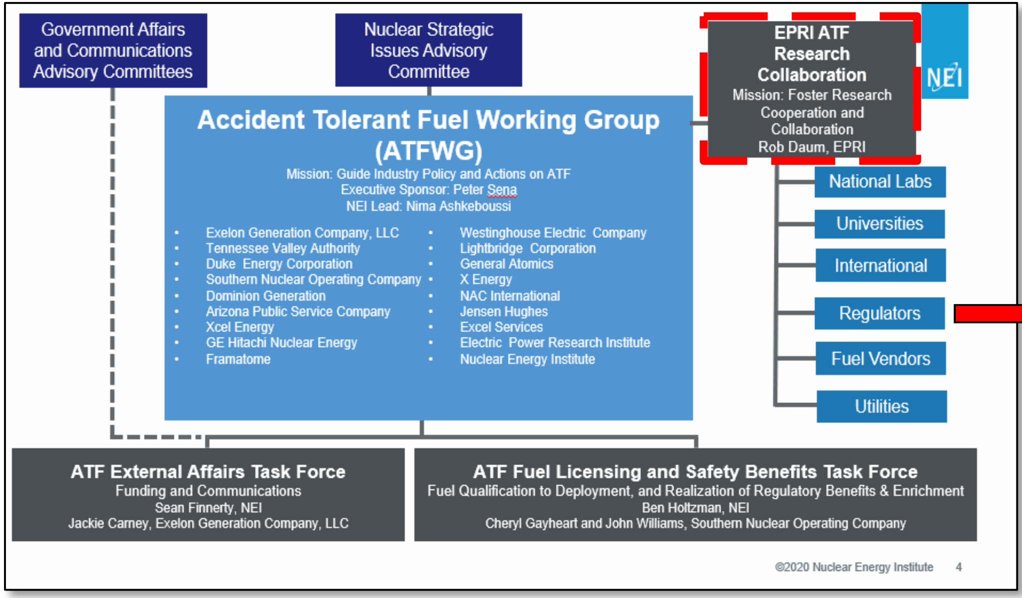
- Gap analyses leading to collaborative and timely research to inform technical and licensing bases



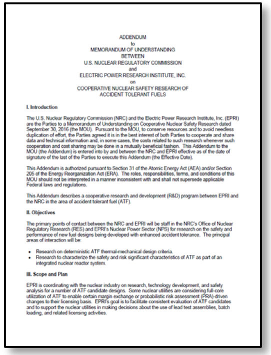
Source: U.S. DOE GC-859 "Nuclear Fuel Data Survey" database converted to peak pin burnup using typical peaking factors and extrapolated to higher burnups and enrichments

CRAFT Mandate and Purpose

- Foster research cooperation, collaboration, and coordination for LWR advanced fuel technologies



EPRI-NRC/RES
MOU Addendum on ATF



ADDENDUM
to
MEMORANDUM OF UNDERSTANDING
BETWEEN
U.S. NUCLEAR REGULATORY COMMISSION
and
ELECTRIC POWER RESEARCH INSTITUTE, INC.
on
COOPERATIVE NUCLEAR SAFETY RESEARCH OF
ACCIDENT TOLERANT FUELS

I. Introduction

The U.S. Nuclear Regulatory Commission (NRC) and the Electric Power Research Institute, Inc. (EPRI) are the Parties to a Memorandum of Understanding on Cooperative Nuclear Safety Research dated September 30, 2016 (the MOU). Pursuant to the MOU, to conserve resources and to avoid needless duplication of effort, the Parties agreed it is in the best interest of both Parties to cooperate and share data and technical information and, in some cases, the costs related to such research whenever such cooperation and cost sharing may be done in a mutually beneficial fashion. This Addendum to the MOU (the Addendum) is entered into by and between the NRC and EPRI effective as of the date of signature of the last of the Parties to execute this Addendum (the Effective Date).

This Addendum is authorized pursuant to Section 31 of the Atomic Energy Act (AEA) and/or Section 205 of the Energy Reorganization Act (ERA). The roles, responsibilities, terms, and conditions of this MOU should not be interpreted in a manner inconsistent with and shall not supersede applicable Federal laws and regulations.

This Addendum describes a cooperative research and development (R&D) program between EPRI and the NRC in the area of accident tolerant fuel (ATF).

II. Objectives

The primary points of contact between the NRC and EPRI will be staff in the NRC's Office of Nuclear Regulatory Research (RES) and EPRI's Nuclear Power Sector (NPS) for research on the safety and performance of new fuel designs being developed with enhanced accident tolerance. The principal areas of interaction will be:

- Research on deterministic ATF thermal-mechanical design criteria.
- Research to characterize the safety and risk significant characteristics of ATF as part of an integrated nuclear reactor system.

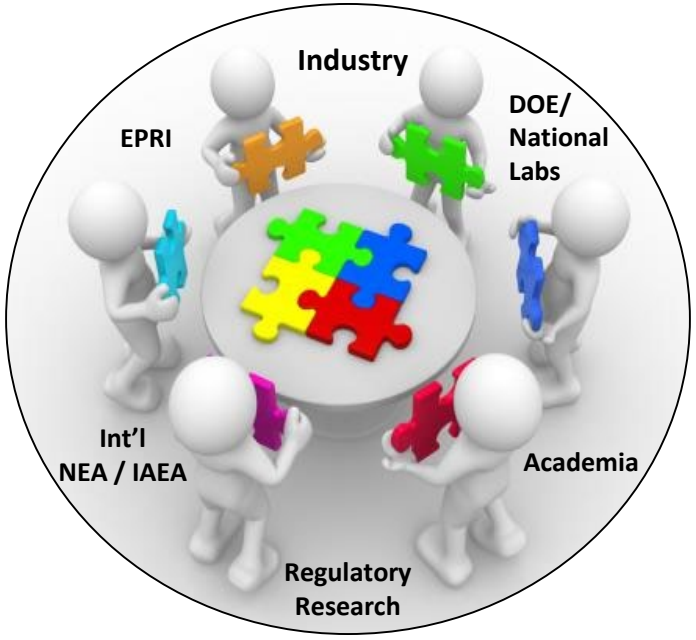
III. Scope and Plan

EPRI is coordinating with the nuclear industry on research, technology development, and safety analysis for a number of ATF candidate designs. Some nuclear utilities are considering full-core utilization of ATF to enable certain margin exchange or probabilistic risk assessment (PRA)-driven changes to their licensing basis. EPRI's goal is to facilitate consistent evaluation of ATF candidates and to support the nuclear utilities in making decisions about the use of lead test assemblies, batch loading, and related licensing activities.

- Emulate the EPRI-led Extended Storage Collaboration Program (ESCP) on dry storage issues

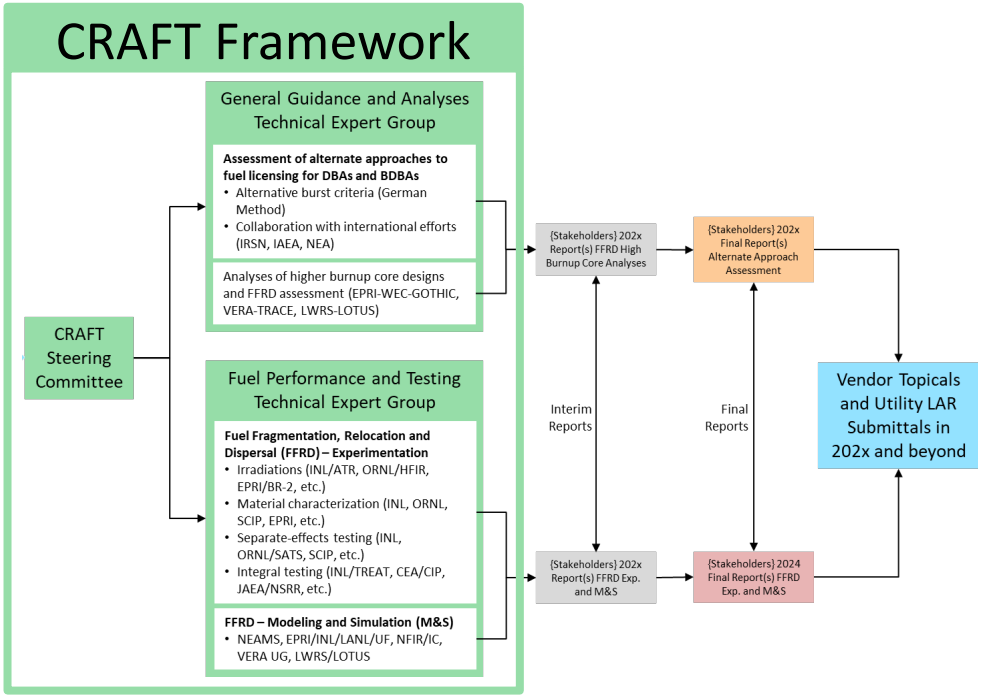
CRAFT Framework Objectives

1. **Bring together subject matter experts** from U.S. organizations, and when appropriate international organizations, engaged with active or planned RD&D in the ATF, higher burnup, and/or higher enrichment fuel areas for LWRs.
2. **Identify both short and long-term technical options and recommendations** for supporting the industry's generic and highest priority RD&D needs for topical and licensing submittals and associated regulatory reviews.
    1. Identify options and recommendations for addressing RD&D issues such as test/resource planning, data collection, and analysis; and determine potential areas for formal collaborations.
    2. Communicate options and recommendations to stakeholders for decision-making activities.
3. **Support gap analyses** and/or Phenomenological Issues Ranking Table (PIRT) processes. Documentation of the gap analyses results are a key part of responsibilities of the collaboration.
4. **Compile, analyze and synthesize generic RD&D results to form/inform technical bases** in targeted deliverables to meet the needs and timelines for submittals and reviews associated with advanced LWR fuel licensing and deployment.



CRAFT Technical Focus and Status

- CRAFT meetings started virtually in 2020 to review/adjust proposal and solicit stakeholder commitments to participate
- Defined a framework charter and issues on in-reactor generic issues associated with Fuel Fragmentation, Relocation, and Dispersal (FFRD)
  - Support higher burnup (~75 GWd/MTU peak rod average)
  - U.S.-focused but will engage international R&D community and stakeholders
- Technical Expert Groups reviewing specific technical issues related to FFRD to develop a coordinated research plan by 3rd quarter 2021
  - Experiments and modeling-simulation
  - Analytical models
  - Risk-informed approaches



Deliverables to Inform Industry, DOE, NRC and the Global Nuclear Community

ESCP & Other Back-End Activities for Advanced LWR Fuels

Hatice Akkurt
Technical Executive
Used Fuel and High-Level Waste Management Program

High Burnup Workshop
June 10, 2021

Extended Storage Collaboration Program (ESCP)

Mission

- **Enhance the technical bases to ensure continued safe, long term used fuel storage and future transportability**

Goals

- Bring together US and International organizations engaged with active or planned R&D in used fuel area
- Share information
- Identify common goals and needs
- Identify potential areas of "formal" collaborations

Phases

- **Phase 1:** Review current technical bases and conduct gap analysis for storage systems
- **Phase 2:** Conduct experiments, field studies, and additional analyses to address gaps
- **Phase 3:** Long-term performance confirmation

ESCP History

2010-2019

Regular May and December meetings, in US

14 International meetings

6 subcommittees

2009

1st ESCP meeting

1 country,

39 participants

2 subcommittees

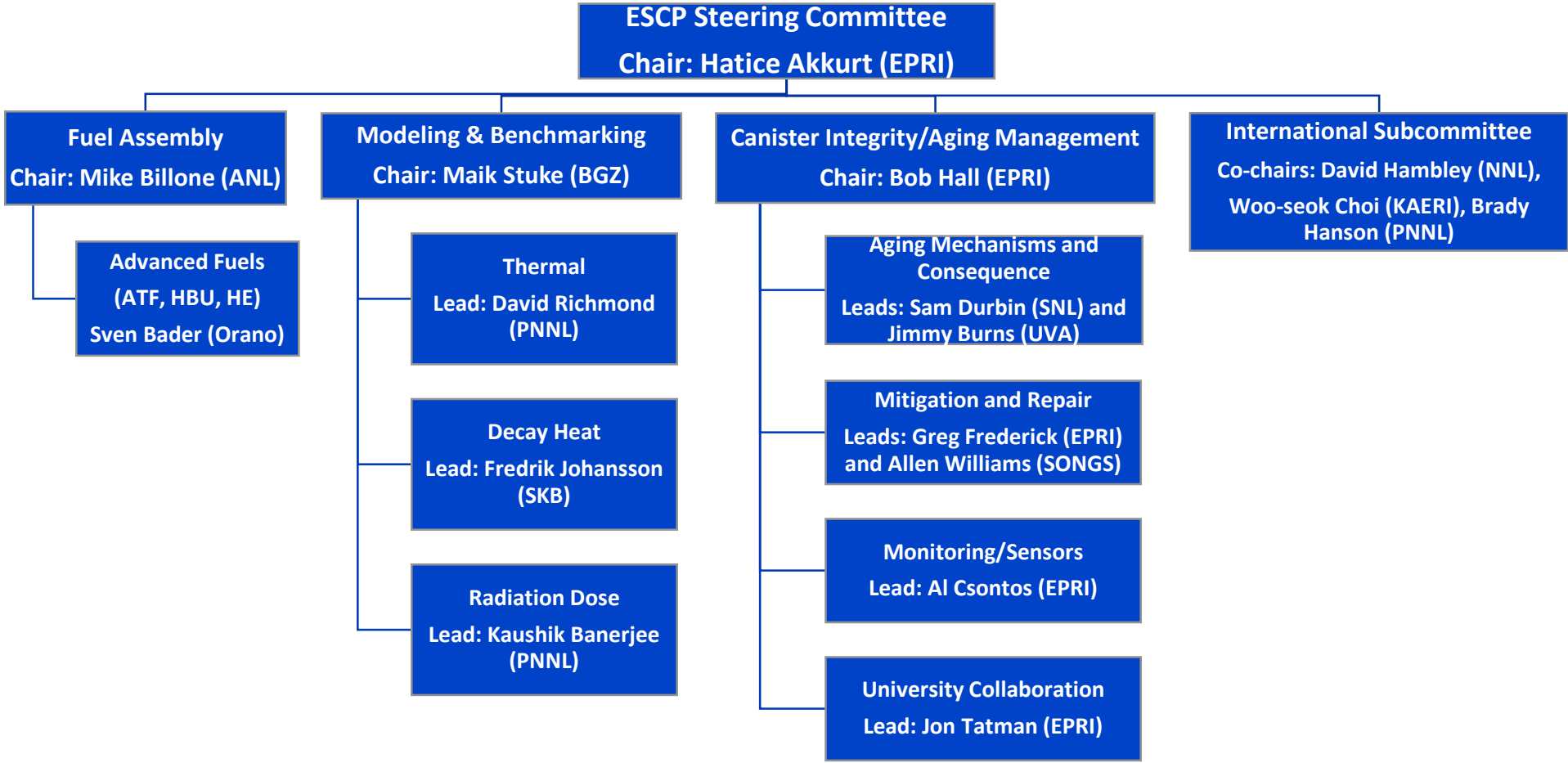
2021

~675 members from **22** countries

Over 315 participants, representing 12 countries, attended Winter 2020 meeting

4 subcommittees

ESCP Structure - Subcommittees (SCs) and Task Groups (TG) – After 2021 Steering Committee Meeting



Activities for Back-end for Advanced LWR Fuel (HBU/HE/ATF)

SFP Criticality

- Formed SFP working group in 2020
- EPRI is leading two generic issues related to SFP criticality
  - Criticality code validation for high enrichment
  - Depletion uncertainty for high burnup
- EPRI reports are anticipated to be published in 2021
- Once reports are published, next step is the regulatory review
  - NEI 12-16 will be revised

Decay Heat Analysis

- EPRI and SKB signed an agreement to publish unpublished CLAB decay heat measurements
- Additional decay heat measurements will be conducted
- These measurement will increase validation space
- Recently started decay heat analysis, via modeling, to evaluate the impact of HBU/HE/ATF
- This work is at early stages

Extended Storage Collaboration program (ESCP)

- Formed Advanced Fuels for LWR task group under ESCP Fuels Subcommittee
- Task group is working toward identification and path for addressing the dry storage related issues for high burnup

EPRI CRAFT General Guidance and Analyses Technical Experts Group (GGATEG)

NRC Higher Burnup Workshop II

June 10, 2021

Bill Gassmann

Exelon Nuclear

Exelon Generation®

GGATEG Charter

- Inform industry, DOE, and NRC of the pressing technical issues regarding deployment of higher burnup and higher enrichment LWR fuel
- Focus on generic research needs to inform issues, including
  - Alternate licensing approaches
  - Safety analyses
  - Core physics and neutronics
- Members include
  - US DOE/National Labs
  - Fuel vendors
  - NRC
  - Utilities
  - NEI
  - EPRI

GGATEG Scope

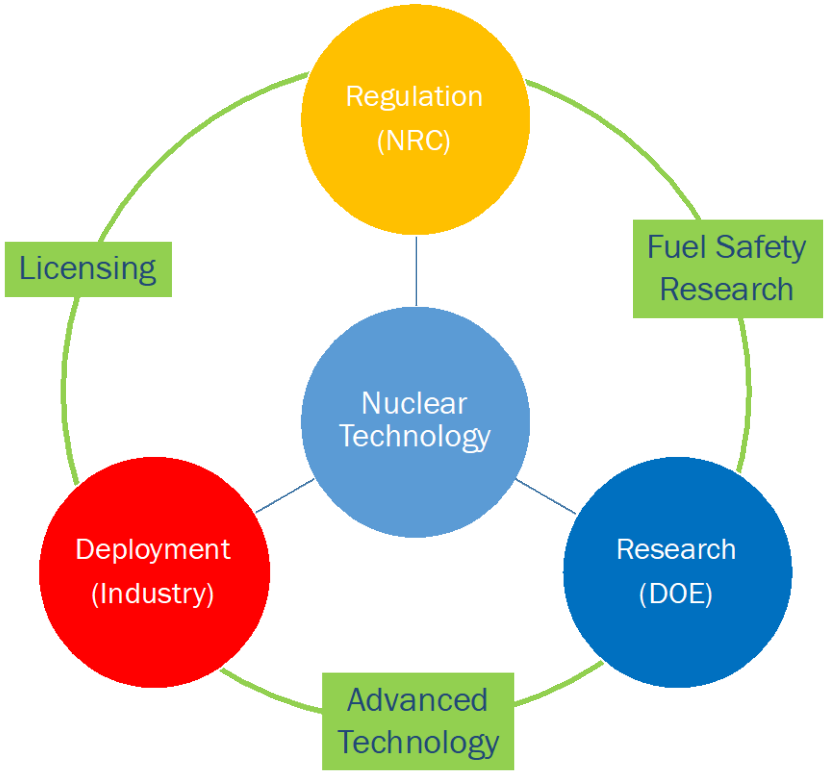
- Research and assessments of generic guidance and alternate approaches for understanding and informing the technical bases for use in industry's fuel licensing submittals and regulator's reviews
  - FFRD
  - Fuel rod burst analyses and consequences under DBAs
  - Higher burnup/enrichment core design analyses
- Investigate existing and new methods and analytical tools for deterministic, best estimate and risk-informed approaches
- Major areas of investigation
  - Fuel relocation
  - Fuel dispersal
  - LBLOCA/xLPR/LBB
  - SBLOCA/IBLOCA
  - Cladding rupture analyses
  - Higher burnup/enrichment fuel management
  - PSA modeling
  - Safety margin evaluation
  - Defense in depth analyses

Update on Fuel Performance and Testing Technical Experts Group

Dr. Daniel Wachs
National Technical Director, Advanced Fuels Campaign
Idaho National Laboratory

NRC High Burnup Meeting
Web meeting, June 10, 2021

Complementary Roles in U.S. Nuclear Technology Enterprise



- Collaboration on Research and Development for Fuel Technology (CRAFT)
  - Fuel Performance and Testing Technical Experts Group (FPT TEG)
  - General Guidance and Analysis Technical Experts Group (GGA TEG)

- TEG Overview
  - Both TEGs are tasked with coordinating technical input and data that can be used to *inform* industrial users, regulators, and researchers
  - TEGs are populated with cross-cutting stakeholder representatives (utilities, fuel vendors, national lab, NRC, EPRI, …)
  - FPT TEG doesn't fund, conduct, or direct independent R&D
  - Information is developed through regular meetings and workshops and transmitted to the CRAFT governing board

Strategy for Next Generation LWR Fuel Technology

- Understanding the relationship between ATF and HBu is important to various stakeholders
- Burnup Extension
  - Phase 1 – Deployment of current fuel designs to 65-68 GWD/MTU
    - Little to no new data required to support licensing
    - Several topicals already submitted
  - Phase 2 – Deployment of current fuel designs to >75 GWD/MTU
    - Must have sufficient data to resolve HBU fuel performance questions (most notably FFRD)
    - Anticipated by mid-2020's
- ATF
  - Deployment of 'near-term' technologies
    - Batch reloads to 'current' regulatory limits by mid 2020's
- Integrated ATF/HBU
  - Deployment of ATF to high burnup w/ optimized utilization margins by ~2030

Current LOCA R&D Needs

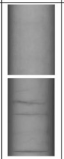
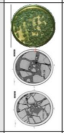
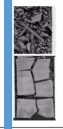
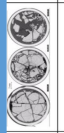
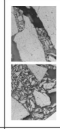
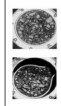
- High burnup fuels (> ~68 GWd/t)
  - Thresholds and extent of fuel fragmentation
  - Thresholds and impacts of fuel relocation
  - Thresholds and impacts of fuel dispersal
  - Reduced uncertainty in transient fission gas release

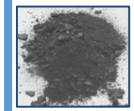
FFRD

- Effect of fully prototypic LOCA conditions temperature evolution (blowdown from full power)
  - No tests to date but differences manifest between in-pile and hot cell LOCA tests

- Integral In-Pile LOCA Testing considered most important R&D need for HBU fuels
- However, additional data needs will naturally be met under this umbrella
  - Expanded HBu fuel performance database (code validation)
  - Confirmatory LOCA Furnace Testing
  - Data for assessment of transient fission gas behavior
  - Validation of RIA performance at HBu

HBU Integral LOCA database (Halden) – 7 PWR, 4 BWR, 2 VVER

test #	7	6	11	10	15	12	13	14*)	3	5	9	4
burnup, MWd/kg	44.3	55.5	56	60	64	72.3	73.1	73.4	81.9	83	90	92
balloon strain, %	23	49	25	15	>60	40	45	60	8	15	61	62
radio-graphy												
ceramo-graphy												
fragment size	coarse	coarse	coarse	coarse & some fine	coarse & fine	coarse & fine	coarse & fine	coarse & fine	medium & fine	medium & fine	medium & fine	medium & fine



72 GWd/MTU from Studsvik furnace test

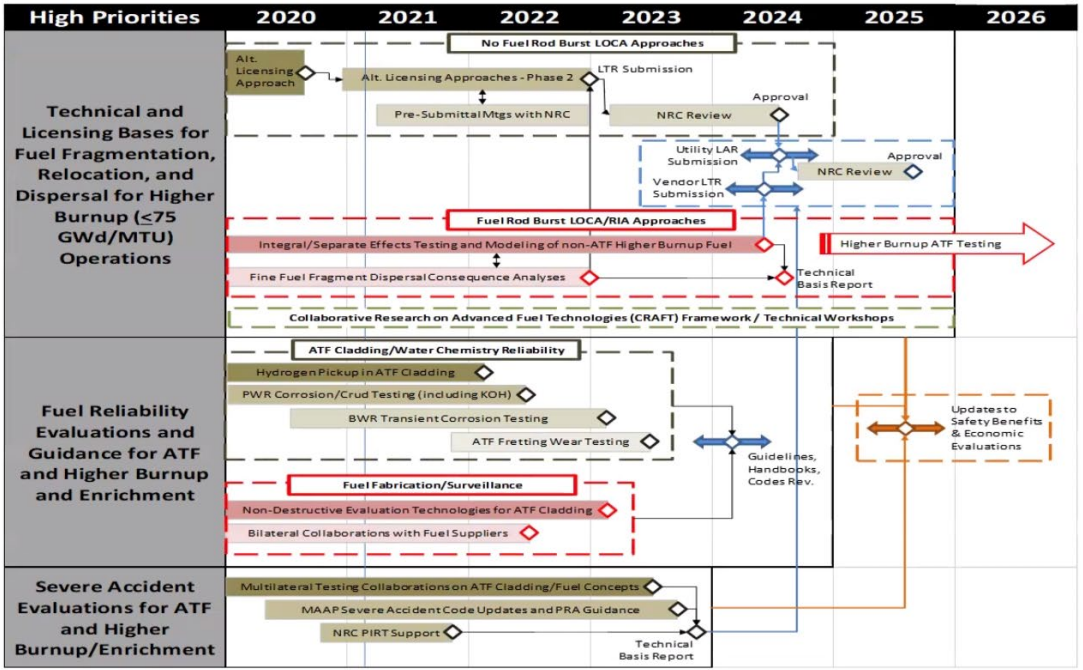
Note: High Burnup BWR data needs are driven by operational behavior rather than licensing

AFC Advanced Fuels Campaign

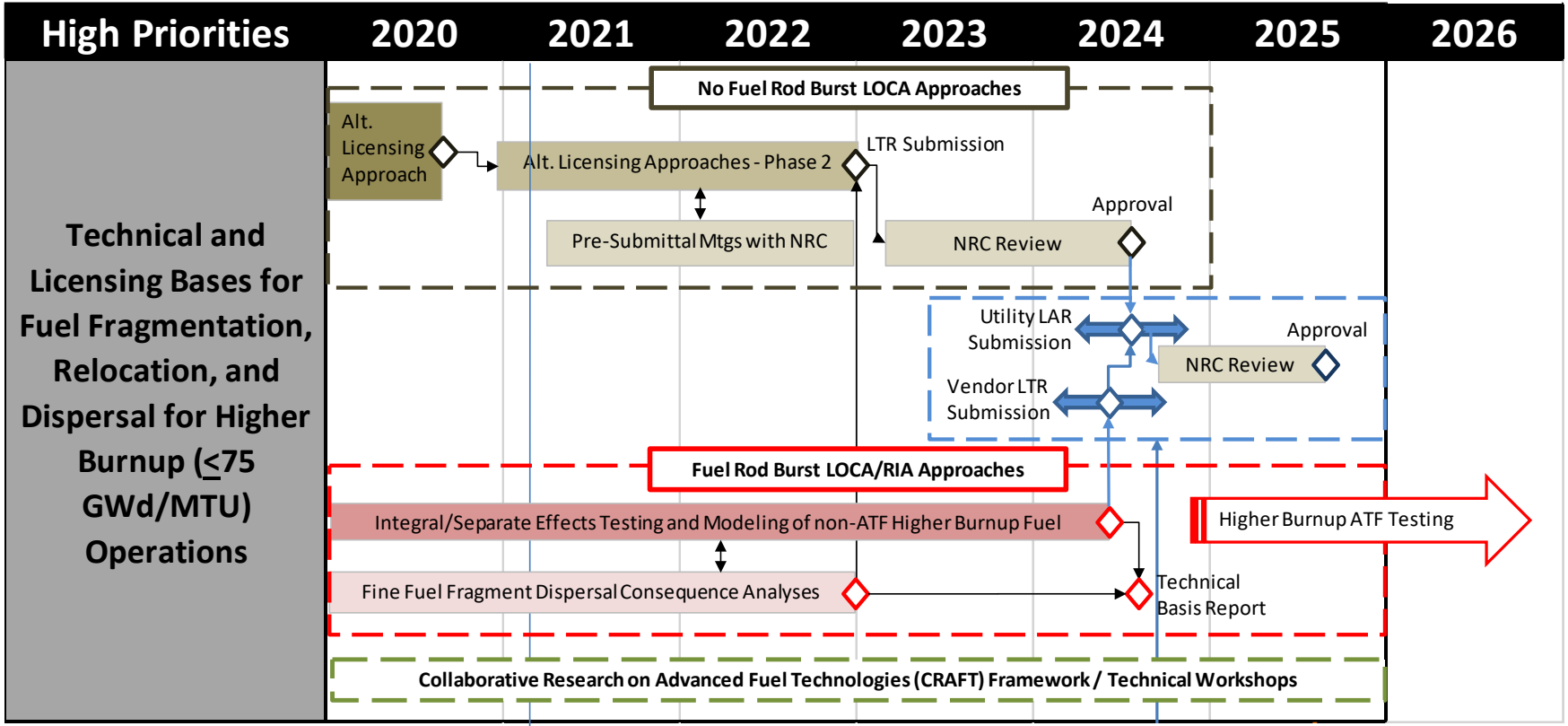
Draft CRAFT HBu Roadmap

R&D Roadmap for Generic Issues

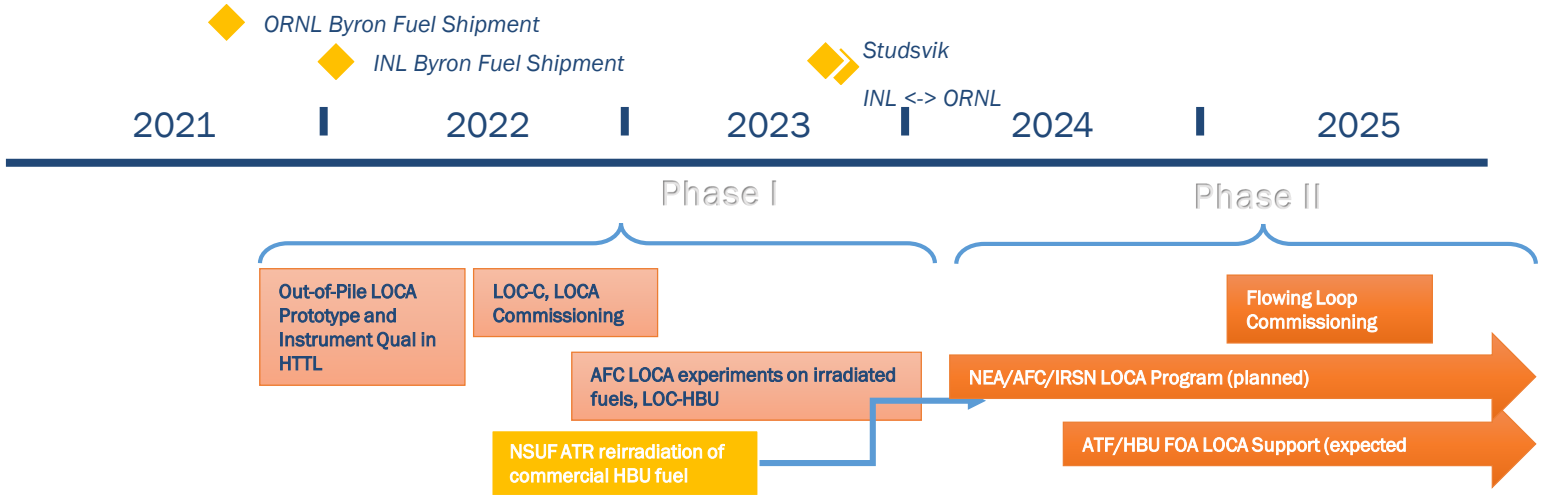
Informing Industry Business Decisions and Licensing Submittals/Reviews



Roadmap for FFRD Assessments



TREAT LOCA Experiment Plan

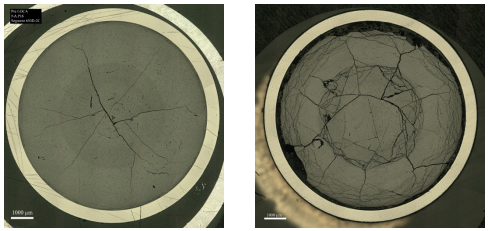


Preliminary LOCA Experiment Matrix

LOC-C: LOCA Commissioning (Fresh Fuel)

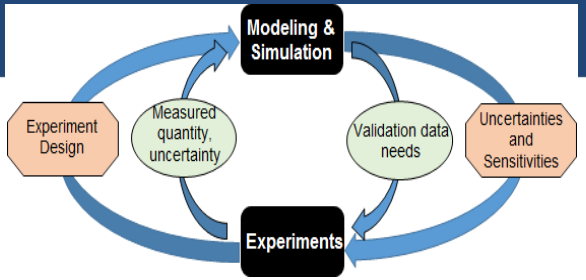
- 2 power calibration tests
- 1 thermal hydraulic characterization test (~5 transients)
- 2 thermomechanical control tests/ATF

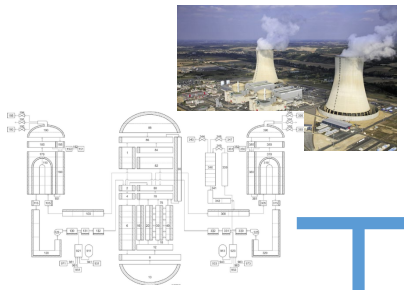
LOC-HBU: High Burnup LOCA Experiments for FFRD*	GWd/t
1 Halden tieback experiment (IFA 650.10, 650.15)	65
1 Prototypic thermal evolution comparison	65
2 Very HBU power history effects tests	75
1 Very HBU doped fuel	75
2 BU limit/beyond	85

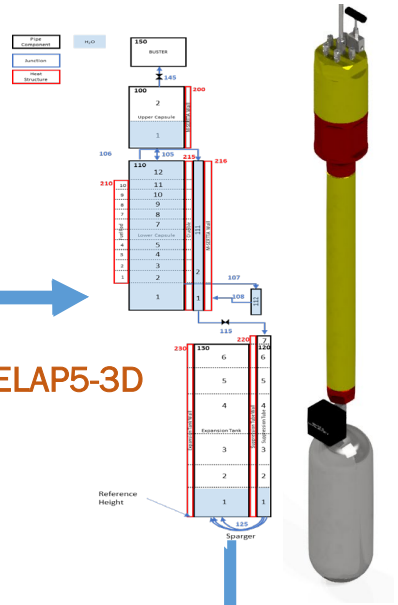


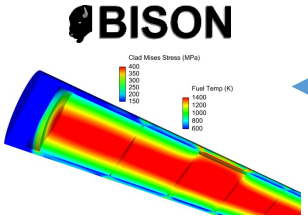
Working with ORNL for complementary hot cell LOCA tests, recent HBU LOCA furnace results shown above, courtesy Jason Harp, ORNL

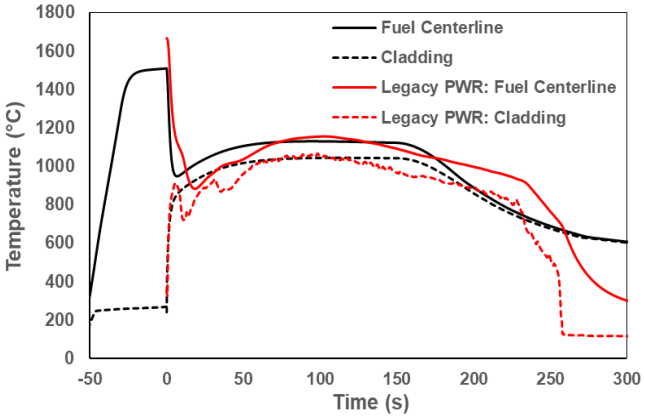
Modeling for Experiment Design





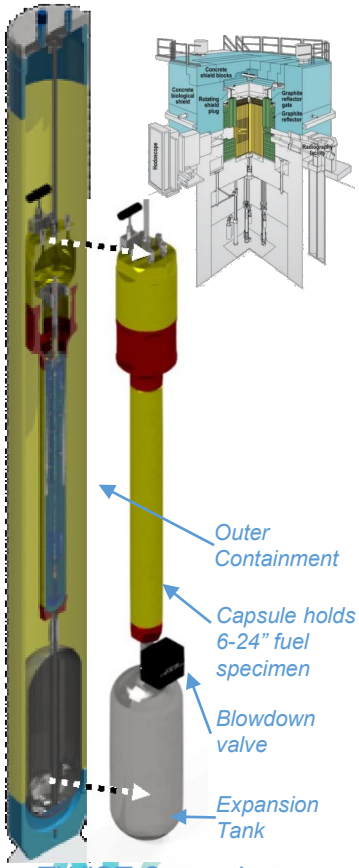






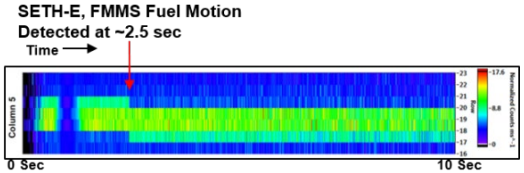
AFC Advanced Fuels Campaign

TREAT LOCA Strategy

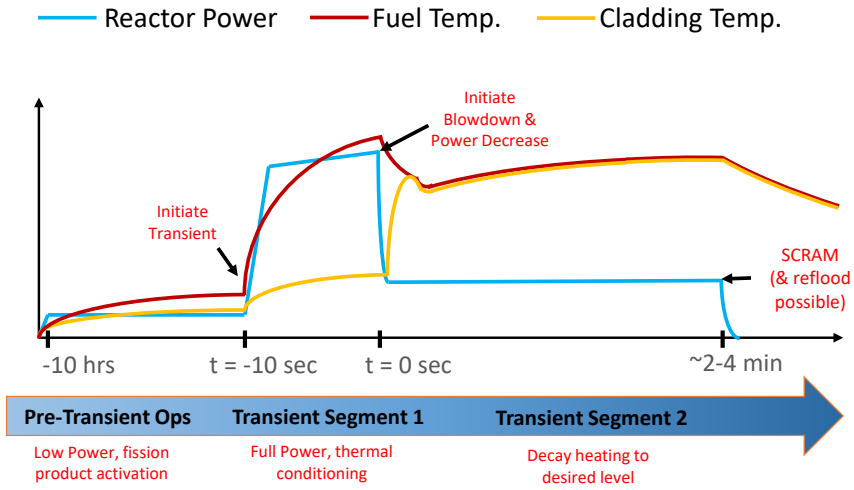


TWIST Capsule

- Designed to provide representative fuel & cladding temperature control
  - 100% nuclear heating in specimen
  - Peak temperatures ~ > cladding melting
  - Heating rate > 2 °C/s



Hodoscope commissioning in SETH experiments



TREAT LOCA sequence

- Unique real-time diagnostics
  - Fuel motion monitoring system
  - Cladding balloon extent
  - Non-contact balloon temperature measurement
  - Fuel centerline temperature
  - Rod plenum pressure (fission gas release)
  - Cladding thermocouples

Summary

- Fuel Performance and Testing TEG is populated with technical leaders from all stakeholders
- Critical path technical questions have been identified and R&D projects to assess them are formulated
- LOCA testing capabilities are in being implemented (in-pile and out-of-pile)
- HBu source materials have been identified and are being sent to the two national labs

Risk-Informed Method for FRRD

NIMA ASHKEBOUSSI, NEI

AST vs Normal Source Term

BEN HOLTZMAN, NEI

ATF Source Term Discussion

- Normal vs Alternate Source Term Method
- Alignment between Reg. Guide 1.183 efforts and industry plans
  - Ensure no artificial restrictive limits
- Will updated source term calculations be required for ATF implementation?

Severe Accident PIRT Impacts

BEN HOLTZMAN, NEI

PIRT Highlights

- No major issues identified for coated cladding, doped UO_2 fuel, or high burnup/enrichment.
- PIRT applied lessons learned from previous coated cladding PIRT for improved process and transparency
- Future engagement on MELCOR and MAAP alignment