High Burnup Alternative Licensing Strategy Update

LOCA induced Fuel Fragmentation, Relocation and Dispersal Topical Report

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Sr. Technical Executive

NRC High Burnup Workshop
August 24, 2022

ALS Objective

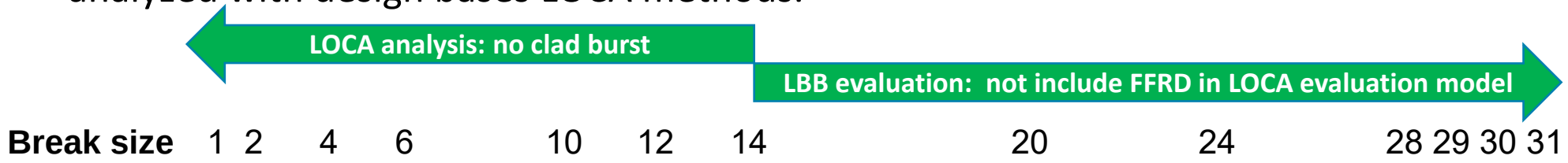
- Obtain NRC approval of generic method to address PWR LOCA induced FFRD in an expeditious manner
  - Avoid reliance on additional LOCA testing
  - Limit licensing complexity and risk
    - Use previously approved methods and licensing strategy to the extent possible
    - Update as needed to address high burnup phenomena
  - Minimize the plant specific implementation activities
    - Confirm applicability requirements apply to specific plant

Safety and Environmental Benefits of ALS

- Provide High Burnup Safety and Environmental Benefits on a more expeditious schedule
  - Reduce risk of transportation accidents across the entire fuel cycle due to reduced volume of special nuclear material
  - Reduced risk of fuel handling accidents within a plant due to smaller reload batch sizes
  - Reduced high level waste to store on site, load into dry cask containers and eventually transport and store in a repository
  - Improved economic performance for nuclear sites reduce the risk of early shutdown; thereby supporting US and international environmental goals of reduced greenhouse gases emissions
  - Improved core design efficiency reduces Uranium environmental and radiological impacts during mining and fuel shipping
  - Higher burnup core designs support longer fuel cycles and lower risk of outage related safety challenges
  - More effective use of limited NRC and Industry resources by avoiding modeling and analysis of fuel dispersal consequences

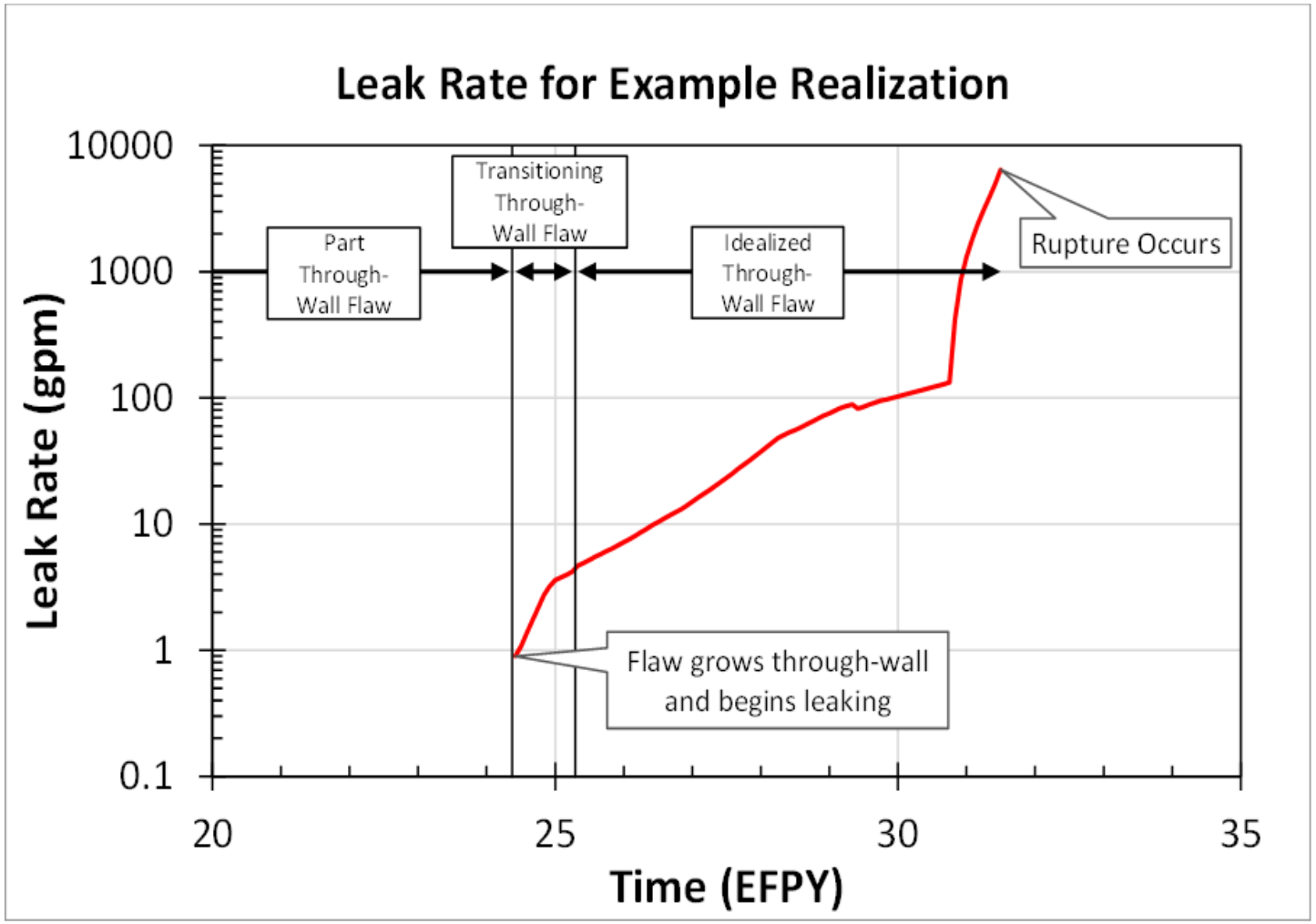
ALS Approach

- Approach to address FFRD in high burnup PWR fuel:
  - Perform small break and intermediate break LOCA analysis to demonstrate no clad rupture and acceptable fuel relocation
  - Realistic treatment of large break LOCAs based on xLPR calculated event propagation and T/S required plant shutdown requirements for LBB qualified piping
- Rationale: LBB has been used to exclude various local phenomena external to RPV (jet impingement, asymmetric vessel loading, failure of ECCS cross-connect valve) and internal to RPV (control rod scram, fuel mechanical loads). Similarly, LBB would be used to exclude FFRD caused by large break LOCA
- Implementation: EPRI will apply xLPR analysis to LBB piping for determining if time available to detect leakage and shut down is sufficient to justify excluding LOCA-induced FFRD. Non-LBB piping analyzed with design bases LOCA methods.



xLPR – Example of Crack Growth to Point of Rupture

- Reactor vessel outlet nozzle, flaw initiates at time 0
- In year 24, leak rate of 1 gpm is detectable and will require shut down
- Stored energy and decay heat drop rapidly after shutdown
- LBLOCA piping rupture would not be expected until 7 yrs. later*
- Even if pipe rupture occurs fuel clad rupture will not occur due to reduction in stored energy and decay heat.



* RCS Pressure and Temperature reduction may not be sufficient to lead to a piping system rupture, seismic and other loads remain potential factors.

Non-piping LOCA events*

- Evaluate failure mechanics/geometry of limiting components and interfacing piping, compare to LOCA analysis rupture size
- Previous evaluations of component failures

LOCA Category	1	2	3	4	5	6
Effective Break Size (in)	0.5 - 1.5	1.5 - 3	3 - 6.75	6.75 - 14	14 - 31	31
Pipe Rupture	SB-LOCA	SB-LOCA	SB-LOCA	IB-LOCA	LB-LOCA (LBB Analysis)	LB-LOCA (LBB Analysis)
Non-Piping Passive Systems	SGTR, CRDM Penetrations, Pressurizer Heater Sleeves	CRDM Penetrations	Nozzles, Component Bodies	Nozzles, Component Bodies*	Man-ways, Component Bodies*	Component Bodies* (BDB)
Active System Components - Stuck Valves (SRV), Pump Seals, Interfacing System LOCAs, Crain Drops						

* Component Bodies Include RPV, Steam Generator, Pressurizer, pumps, valve bodies

*Note: Existing LBB applications do not address non-piping LOCA events

ALS scope

- ALS is based on a realistic treatment of the potential for LB-LOCA generated FFRD
- ALS does not modify ECCS system design or analysis for non-FFRD LOCA evaluations
  - ECCS design bases heat removal and mass replacement capability are not modified
  - Other events (Fuel handling, RIA) are not addressed in the scope of ALS
- LBB Credit is only applied to piping systems already qualified for LBB applications
  - Material performance and fracture mechanics analysis previously approved by NRC
  - Leak detection capability has been established
  - Supports conclusion that the specific piping system has an extremely low probability of rupture
- Clad rupture is expected to be precluded but should it occur the associated dispersal is a result of the dynamic effects (temperature and pressure) of the piping system rupture
- Clad rupture and dispersal is a local phenomena, similar to the LBB based evaluation of loads on individual fuel pins during blowdown

Recent Activities

- **xLPR NRC Public Meeting Briefing 6/14/22***
- Scope
  - Development of LOCA Frequencies – NUREG-1829
  - NRC Experience using xLPR
  - EPRI use of xLPR to support ALS
    - Phase 1 – xLPR Proof of Concept 2021
    - Use of LOCA Frequency Estimates in ALS
    - Phase 2 - Full Spectrum xLPR analysis 2022
- Result
  - NRC provided feedback/suggestion on specific areas of EPRI xLPR project plans
  - Follow up xLPR progress
    - Additional Public meeting as results are near completion
  - NRC highlighted the need for similar deep dive into ALS project from Fuel Perspective

- June 14 Public Meeting with EPRI to discuss use of the xLPR code for LOCA estimates. All the meeting presentation slides are now available publicly via ADAMS (ML22166A345) and the link to the slide package is given below:
- https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML22166A345 [adamswebsearch2.nrc.gov]

Additional NRC engagements

- NRC High Burnup Workshop August 24, 2022
- Pre-submittal meeting: target date August 30, 2022
  - Proposed Licensing Approach
    - LOCA Methods Adjustments to address high burnup effects
    - Generic NSSS Design Development
    - LBB treatment for LBLOCA
    - Treatment of Non-piping failures
  - Analysis Methods and Scope
  - Acceptance Review Expectations
  - Submittal Schedule
- Fee Waiver Request

ALS Scope/Schedule

- FFRD LOCA analysis to include Small and Intermediate Breaks
  - Consistent with LBB applications
    - Limiting branch lines are the Accumulator Line Break (Cold Leg) and Pressurizer Surge Line (Hot Leg)
- Address non-piping LOCA
  - Non-Piping Breaks – manways, component bodies, nozzles, heater sleeves
  - Active system Failures – Stuck open valves (SRV), pump seals
- Schedule
  - Submittal 4th quarter 2023

Utility Perspectives on EPRI High Burnup ALS Strategy

NRC High Burnup Workshop

24-August-2022

Johnathan Chavers

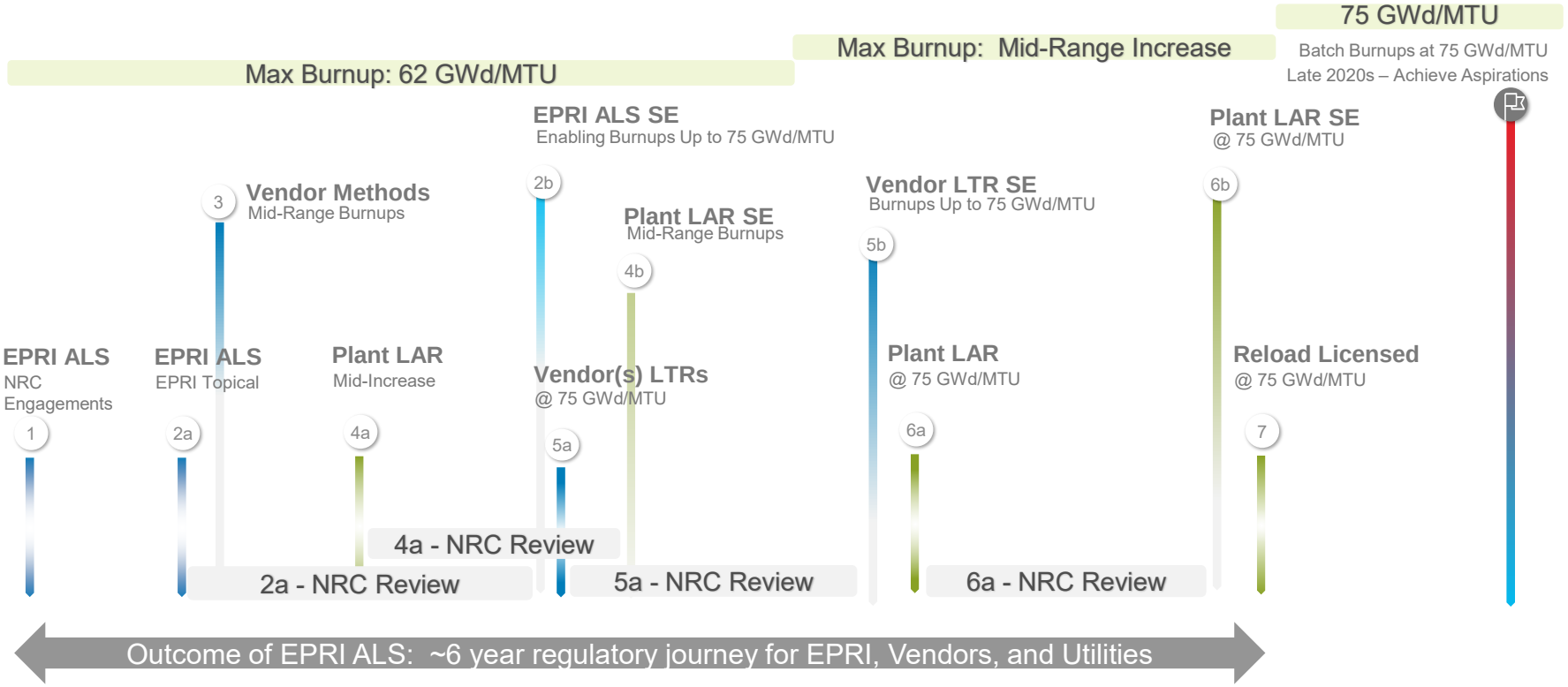
Nuclear Fuel & Analysis Director, Southern Nuclear

Southern Nuclear

Strategic Aspirations... A Utility Perspective

- Develop and deploy fuel technologies that incrementally enhance accident tolerant features and operational margins while enabling sustained economic performance through minimizing cost and improving efficiency.
- Achieve fuel licensing infrastructure to support burnup and enrichment extensions (LEU+) beyond legacy limits in the mid-2020s.
- Modernize global supply chain to support LEU+ reloads in the mid-2020s.
- Safely and economically enable 24-month cycle operation for the entire fleet of existing light water reactors. [Burnups up to ~75 GWd/MTU]
- Preserve and enhance the existing fuel technologies resiliency to fuel cladding perforations during operation.
- Commercialization and economies of scale of advanced fuel technologies through sustainable volumes.

Achieving Strategic Aspirations
Sample Burnup Extensions to 75 GWd/MTU for a Generic PWR leveraging EPRI Licensing Strategy



Our Path… A Utility Perspective

- **EPRI's High Burnup Alternative Licensing Strategy**
  - Provides a consistent and streamlined generic approach for PWRs
  - Scope is well confined to address the most significant generic issue with increases in burnup
  - Most prudent path with resources (ATF-DOE Program, Vendors, Utilities, NRC)
  - Current "critical path" to achieving our aspirations

- **Additional Considerations**
  - Regulatory Guide 1.183 Rev. 1 – aspire for additional revision parallel path for 75 GWd/MTU
  - Many other vendor and plant specific licensing interactions with incremental progress

Update on the Collaborative Research on Advanced Fuel Technologies for LWRs (CRAFT)

Rob Daum, EPRI
Bill Gassmann, Constellation
Colby Jensen and Dan Wachs, INL
Nathan Capps, ORNL

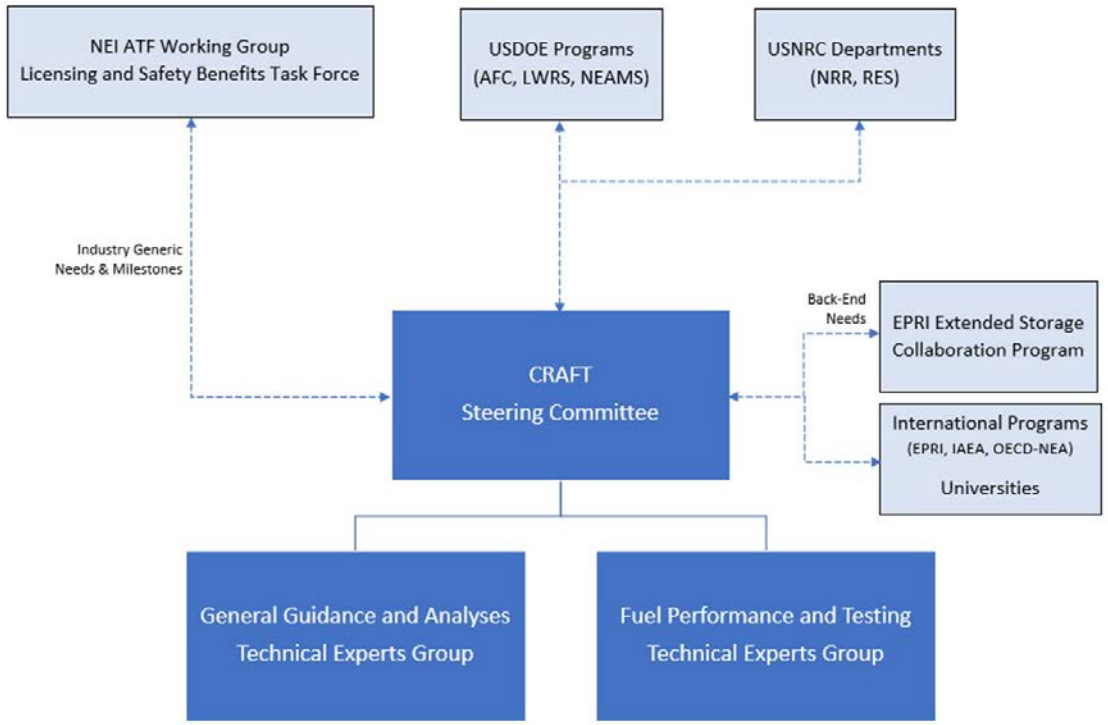
NRC Higher Burnup Workshop III
August 24, 2022

CRAFT Mission and Structure

- Support the **technical and research needs of U.S. stakeholders** through:
  - NEI ATF Working Group organizational structure
  - NRC/RES-EPRI Memorandum of Understanding
  - Various DOE-EPRI agreements

- CRAFT provides **technical exchanges, expert analyses, and bases** for addressing **generic issues of fuel behavior and performance during in-reactor operations** as identified by stakeholders to **inform deployment of advanced LWR fuel technologies** (i.e., accident tolerant fuel (ATF) with higher enrichment and burnup).

- The identified generic in-reactor issues will be continuously discussed within CRAFT, and therefore be used to define the CRAFT technical scope which will evolve as **these issues are identified, prioritized, and dispositioned**.



Current focus on LOCA-induced Fuel Fragmentation, Relocation, and Dispersal (FFRD)

CRAFT Major Activities

- Further refine technical issues and attributes using the CRAFT Issue Tracking Matrix (ITM)
  - Emphasis on Fuel Fragmentation, Relocation, and Dispersal (FFRD)
  - Review FFRD Elements and Thresholds from NRC-RES Research Information Letter (RIL) 2021-13
- Develop draft R&D roadmap of FFRD ITM issues
- Review DOE-AFC LOCA Higher Burnup Test Plan
  - Develop consensus agreement among CRAFT stakeholders
- Brainstorm FFRD research topics for consideration of DOE Nuclear Energy University Program

2022 CRAFT Deliverables

- Input for DOE consideration into NEUP technical areas (informal communication to DOE and NEI) – Q2
- Consensus DOE-AFC LOCA Test Plan (formal report) – Q3
- Peer review of white paper on FFRD experimental database (informal communication to EPRI) – Q3/Q4
- CRAFT ITM Roadmap report (informal “living” report) – Q4

CRAFT Issue Tracking Matrix

Focus on Fuel Fragmentation, Relocation, and Dispersal under Postulated Design Basis Accidents

CRAFT Issue Tracking Matrix (ITM)

- Serves as a “living” tool for capturing generic technical issues and attributes of advanced fuel technologies, including Accident Tolerant Fuel, Higher Burnup, and Increased Enrichment
  - Stakeholders focused on FFRD at higher burnup and during postulated design basis accident conditions
- Provide experts reviews and interpretation of technical bases for informing stakeholders on licensing bases and potential consequence analyses
  - Deterministic / Best Estimate usage of FFRD experimental database and modeling/simulation
  - Risk-informed or alternate approaches
- ITM issues and attributes assigned to two Technical Expert Groups (TEGs):
  - Fuel Performance and Testing
  - General Guidance and Analyses

Continuously Reviewed and Updated with Latest Understanding and Stakeholder Needs

CRAFT ITM – Research Evaluation Activities

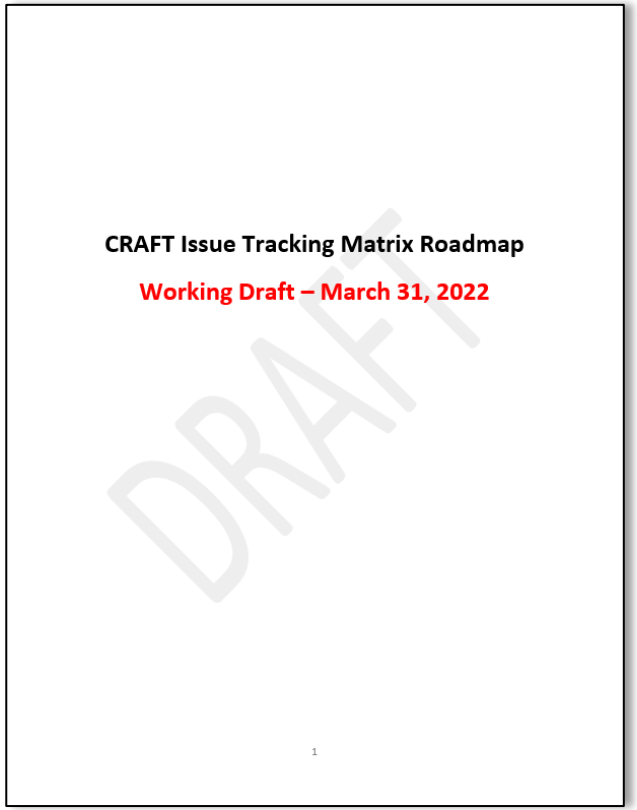
- **Fuel Fragmentation (Pulverization)**
  - Higher burnup PIE
  - Advanced fuel characterization and tests
  - In- and out-pile testing
  - Transient Fission Gas Release testing
  - Modeling / Simulation
  - Quantification of fuel susceptible to fragmentation
- **Fuel Relocation**
  - Clad balloon propensity, size, and dynamics
  - Effect of rod internal pressure and clad creep and associated thermal ramp conditions
  - No rupture and rupture cases
  - Quantification of fuel susceptible to relocation
  - Acceptability and applicability of relocated fuel (core, ATF, non-ATF)
- **Fuel Dispersal**
  - Experimental methodologies for quantifying fragment dispersal
  - Quantification of fuel susceptible to dispersal
  - Acceptability and applicability of dispersed fuel (core, ATF, non-ATF)
  - Tracking of dispersed fuel
  - Consequence analyses of dispersed fuel

Fuel Performance and Testing TEG

General Guidance and Analyses TEG

ITM Spreadsheet & Roadmap Document

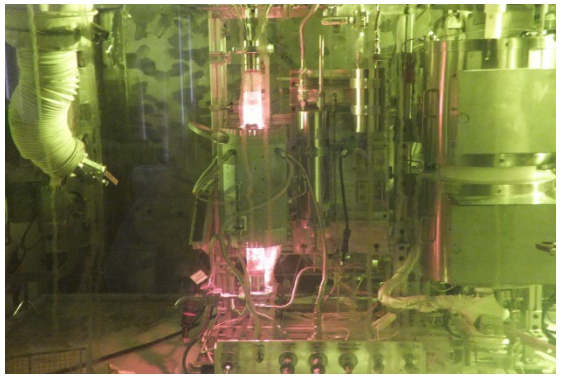
- Reviewed highly preliminary draft document and schedule for issuing Rev. 0 at Q2 meeting
- TEGs continue to refine with Attribute Integrators in Q2 – Q4
  - Incorporation and follow-on analyses of NRC's RIL published database
  - Coordination/collaboration with OECD/NEA projects
  - Need to continue to capture stakeholder activities and timelines
- Next draft of Rev. 0 to be discussed and presented to SC in Q4
  - Likely delay in soliciting SC endorsement for formal issuance of Rev. 0 so slippage into Q1/Q2 2023



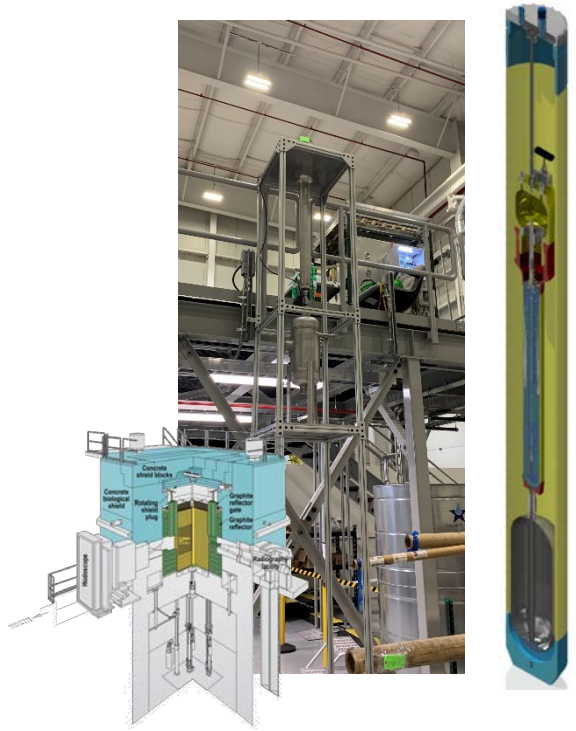
Consensus Agreement on DOE-AFC LOCA Test Plan

DOE-Industry LOCA Test Plan

- Combined integral and semi-integral LOCA test plan developed to address broad stakeholder needs
  - Leverages the best PIE capabilities in the U.S.
- Goal to address cross-cutting stakeholder needs
- Primary emphasis on experimental evaluation of identified R&D gaps in FFRD in a LOCA
  - First of a kind approach using both in-pile and hot cell testing facilities
  - Novel in-situ instrumentation
    - Fuel motion monitoring, tFGR, balloon extent and surface temperature



Severe Accident Test Station



TREAT TWIST LOCA Device

2023 | 2024 | 2025 | 2026 | 2027

TREAT LOCA Device Design, Fabrication, and Testing

TREAT-LOC-C Fresh Fuel, In-Pile LOCA Commissioning

3 years, ~ 10(x2) experiments

TREAT-LOC-HBu and SATS-HBu
(Testing high burnup fuels from 65-85 GWd/t)

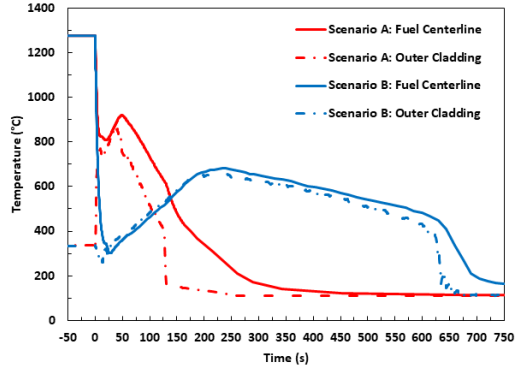
- **Tieback testing to Halden/SCIP**
- **DEH and SEH heating conditions**
- **Doped fuel**
- **Plenum/axial gas communication effects**
- **Pre-accident power effects**

NSUF ATR reirradiation of commercial HBU fuel

AFC Advanced Fuels Campaign

Consensus LOCA Test Plan

- Recent Transient Reactor Test (TREAT) Facility restart and closure of the Halden Boiling Water Reactor raised DOE priority for development of in-pile integral LOCA testing capability
- DOE Advanced Fuels Campaign (AFC) program led critical review on topic of FFRD in LOCA to highlight main conclusions and identify potential R&D gaps and opportunities
- Fuel Performance Testing Technical Expert Group (FPTTEG) performed R&D prioritization survey
  - Need for integral LOCA testing ranked highest of ~ 10 identified R&D areas
- Stakeholders (fuel vendors) requested to provide input for experiment design via input on needs and reference prototypic boundary conditions
- Fully expect test matrix evolution during plan execution



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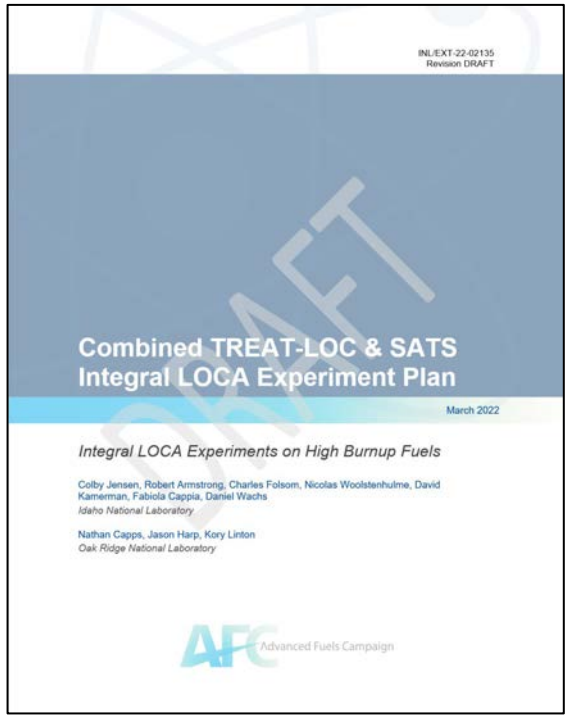
EPRI

Stakeholder Feedback on Draft Plan

- Written feedback received from DOE, EPRI, WEC, Framatome, NRC, (verbal feedback from GNF)
  - 13 full pages of written comments
- Differing interests from reviewers though most interests seem to be captured in the test matrix to some level
  - Contrasting interests in focusing on “traditional LOCA experiment” DEH condition (“slow” ramp rate ~5 K/s heat up) vs also evaluating SEH condition, (“fast” initial heat up)
  - Prioritization of tieback testing and in-pile vs out-of-pile evaluations
  - Some comments imply interest LOCA conditions may need to be included
    - Plan purposefully prioritizes and focuses on LB LOCA conditions
- Concerns about test results from new facilities/experimenters
- General comments and clarifications regarding QA, process for future plan revisions, and so on.
- Ongoing 1-1 meetings with stakeholder where needed/requested



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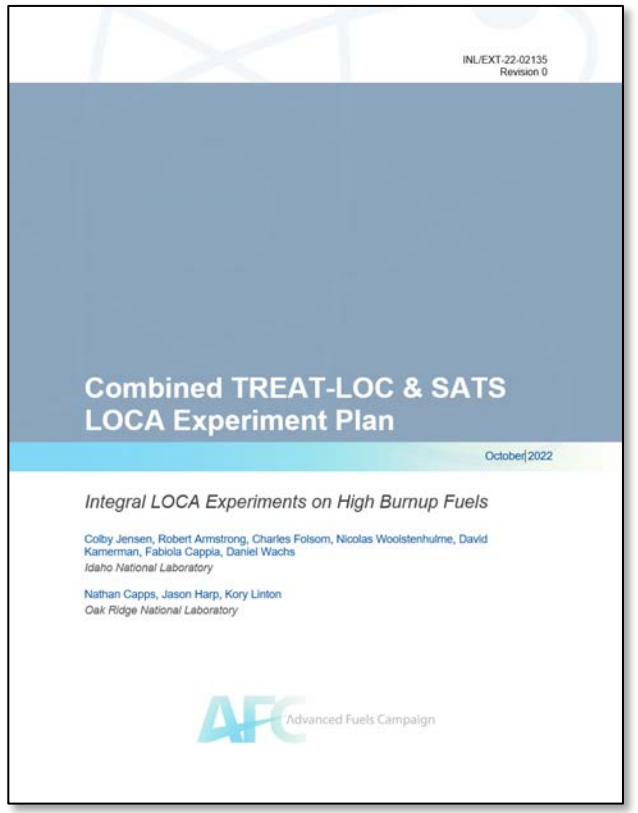
Completion Schedule for LOCA Test Plan Rev0

- Initial draft test plan sent to stakeholders through the FPT TEG on 3/26
- CRAFT Q1/Q2 meeting decided that all stakeholders to provide comments back to INL/ORNL by 4/29
- FPT TEG met on 5/18 and INL/ORNL briefed TEG members on the review comments/questions received to-date and set schedule for finalizing the test plan within CY2022
- Ongoing step is for INL/ORNL to address specific review comments using a comment resolution process, which involves one-on-one discussions with stakeholders in the event further discussion of comments is warranted
- Next version of the draft test plan with resolution of comments to be presented to the FPT TEG in early September
- Final version of consensus test plan to be endorsed by CRAFT Steering Committee stakeholder members and made available by end of September
  - Pending any potential issues in achieving consensus from the group



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Planning for Next CRAFT Meetings

Meetings for Remainder of 2022

- Q3/Q4 Virtual TEG Meetings (as needed)

- Q4 Hybrid Meeting
  - Thursday, Nov. 3rd at Constellation's Cantera office in Warrenville, IL (30 miles west of Chicago)
    - Held in coordination with Open Fuels Session of DOE Nuclear Energy Advanced Modeling and Simulation (NEAMS) Annual Review Meeting on Wednesday, Nov. 2nd at the Gleacher Center in Downtown Chicago
  - Save-the-Date and Invitations forthcoming
    - Note, EPRI will provide ground transportation between Chicago and Warrenville on evening of Nov. 2nd and/or early morning of Nov. 3rd depending on registration response