U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Regulatory Basis on Increased Enrichment of Conventional and Accident Tolerant Fuel Designs for Light-Water Reactors

November 2, 2023

Opening Remarks

Scott Krepel
Branch Chief
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U.S.NRC
United States Nuclear Regulatory Commission
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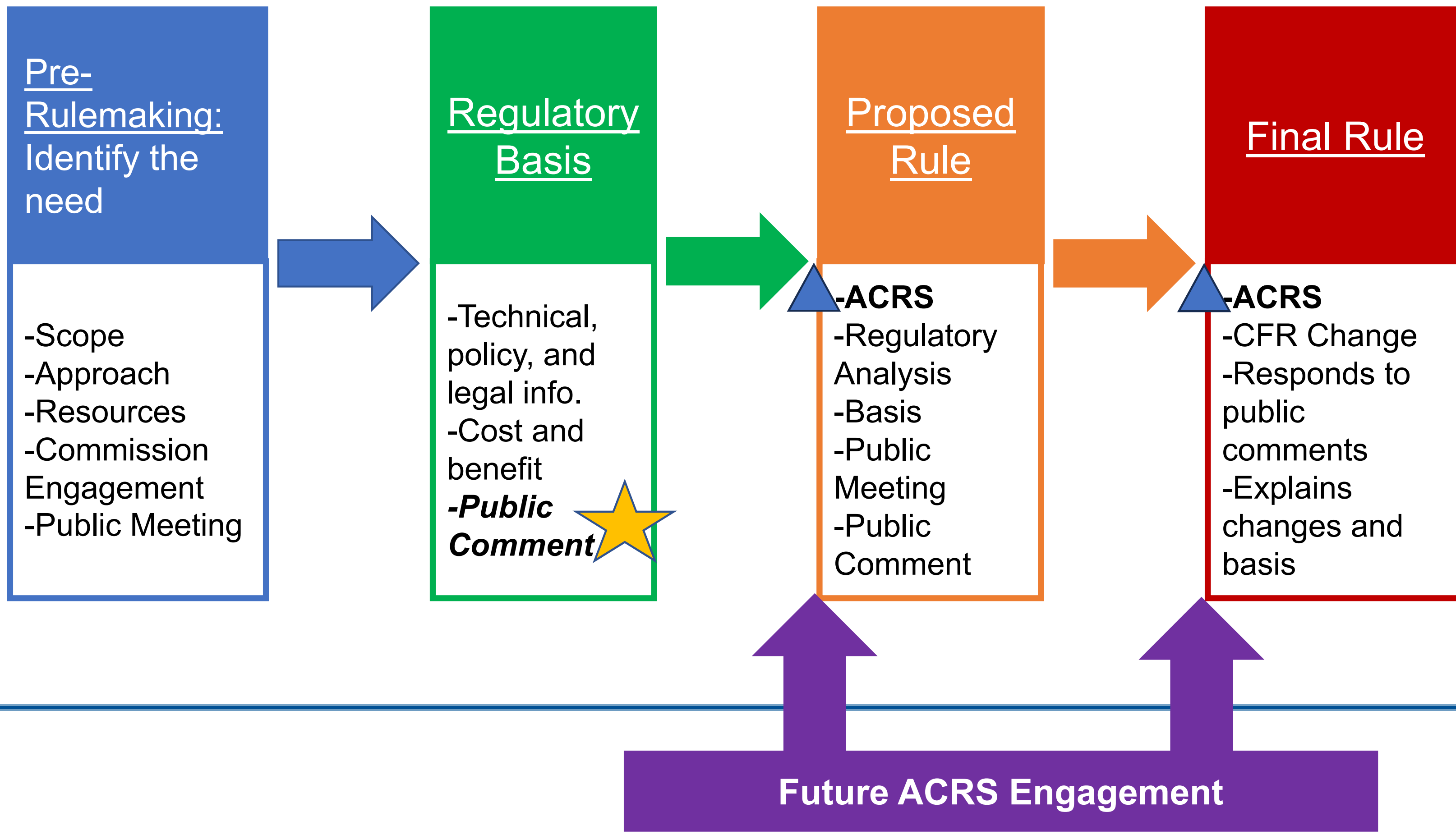
NRC Staff Presenters

- **Philip Benavides, NMSS:**
  - Overview of Increased Enrichment Rulemaking
- **Charley Peabody, NRR:**
  - Criticality Accident Requirements (10 CFR 50.68)
- **Philip Benavides on behalf of Don Palmrose, NMSS:**
  - Environmental Regulations in 10 CFR 51.51 & 10 CFR 51.52
- **Jason Piotter, NMSS:**
  - General Requirements for Fissile Material Packages (10 CFR 71.55)
- **Elijah Dickson, NRR:**
  - Control Room Requirements (10 CFR 50.67 and GDC-19)
- **Joseph Messina & Ashley Smith, NRR:**
  - Fuel Fragmentation, Relocation, and Dispersal

Overview of Increased Enrichment Rulemaking

Philip Benavides
Project Manager
Reactor Rulemaking & Project Management Branch

Rulemaking Process



Issue Identification

- **Regulatory Issue:**
  - Current licensing framework allows for the use of > 5 weight percent uranium-235; however, technology developments may require numerous exemptions to utilize fuel enriched above 5 weight percent uranium-235.
- **Proposed Solution:**
  - Rulemaking would provide for a generically applicable standard informed by public input, providing consistent and transparent communication, rather than individual licensing requests as discussed in SECY-21-0109, Rulemaking Plan on Use of Increased Enrichment of Conventional and Accident Tolerant Fuel Designs for Light-Water Reactors.
- **Commission Rulemaking Plan Approval:**
  - Staff request to the Commission to pursue rulemaking and develop a regulatory basis was approved by the Commission via SRM-SECY-21-0109 on 3/16/2022.

Status of Rulemaking Activity

- **The NRC staff issued a regulatory basis on September 8, 2023**
  - Discusses regulatory issues and alternatives to resolve them
  - Considers legal, policy, and technical issues
  - Considers costs and benefits of each alternative
  - Identifies the NRC staff's recommended alternative for most regulatory issues
    - FFRD: Alternatives offered with no recommendation at this time
- **ACRS Fuels, Materials, and Structures Subcommittee: October 18, 2023**
- **Stakeholder Involvement:**
  - Public Meetings held on June 22, 2022 & October 25, 2023
  - Comment Period until November 22, 2023
- **Proposed rule due to the Commission: December 2024**

Regulatory Basis Topics

- **The regulatory basis describes the evaluated technical topics:**
  - Criticality Accident Requirements (10 CFR 50.68)
  - Uranium Fuel Cycle Environmental Data - Table S-3 (10 CFR 51.51)
  - Environmental Effects of Transportation of Fuel and Waste - Table S-4 (10 CFR 51.52)
  - General Requirements for Fissile Material Packages (10 CFR 71.55)
  - Control Room Requirements (10 CFR 50.67 and GDC-19)
  - Fuel Fragmentation, Relocation, and Dispersal

Criticality Accident Requirements of 10 CFR 50.68

Charley Peabody
Nuclear Systems Performance
NRR

Criticality Accident Requirements of 10 CFR 50.68: Summary of Regulatory Issue

- Rule utilizes k-effective acceptance criteria with required probability and confidence levels to permit exemptions to 10 CFR 70.24 active criticality monitoring and emergency planning requirements
- Current rule limits application to enrichments of ≤ 5% weight Uranium-235

10 CFR 50.68: Recommended Alternative

Staff Recommends Alternative 3: replacing the current enrichment limit with the Technical Specifications Design Feature limits

- Maintains existing subcriticality margins at the same k-effective probability and confidence levels
- Criticality safety impacts are addressed during the fuel transition license amendment request process
- Allows consideration of low-enriched uranium up to <20.0% weight
- Research Study with Oak Ridge National Laboratory
- Preserves the § 50.68(b) compliance for all existing fleet without backfit

Questions

Environmental Requirements of 10 CFR 51.51 & 51.52

Donald Palmrose
Environmental Review New Reactors Branch
NMSS

Environmental Requirements of 10 CFR 51.51 & 51.52 Summary of Regulatory Issues

- The environmental data of Table S-3 (10 CFR 51.51(b)) and environmental impacts of Table S-4 (10 CFR 51.52(c)) are bounding for enrichments up to 5 wt % U-235.
- Currently no approved assessment of environmental impacts related to the uranium fuel cycle or transportation of fresh unirradiated fuel for increases greater than 5% U-235.
- NUREG-2266 is a draft report for comment that would support these tables to bound up to 8 wt % U-235
- Until further environmental evaluations are completed:
  - For Table S-3, advanced reactor construction and operation licensing requests could involve use of up to 20% U-235 and require case-by-case reviews.
  - For Table S-4, reactor licensing requests with shipments of fresh fuel with more than 5 wt % U-235, there would need to be a full description and detailed analysis of transportation impacts as directed by 10 CFR 51.52(b).

10 CFR 51.51 and 51.52: Alternatives

1. *No Action* - Maintain current regulatory framework by assessing environmental impacts from the uranium fuel cycle on a case-by-case site-specific basis
2. *Rulemaking* - Pursue the necessary environmental analysis to justify continued use of Table S-3 and Table S-4 for increased enrichment and then pursue rulemaking to modify both tables (**recommended**)
3. *Rely on Revised or Updated Environmental Analysis* - Rely on the updated analysis when reviewing licensing actions for the use of increased enrichment fuels

Questions

Packaging Requirements of 10 CFR 71.55

Jason Piotter
Containment, Thermal, Chemical & Fire Protection Branch
NMSS

10 CFR 71.55: Options for seeking approval by Certificate of Compliance

(1) Evaluate UF_6 packages with optimum moderation § 71.55(b)

- current package design
- redesigned package

(2) Request an exemption to § 71.55(b)

\- Exceptions to § 71.55(b)

(3) Request approval under § 71.55(c) **(Requires special design feature and adm. controls.)**

(4) Request approval under § 71.55(g) **(enrichment limited to 5 weight percent U-235)**

10 CFR 71.55: Rulemaking Alternatives

1. *No Action* - Utilize Existing Certificate of Compliance Options
2. *Rulemaking* - Increase Enrichment limit to < 20.0% wt U-235
3. *Rulemaking* - Remove Enrichment Limit

10 CFR 71.55(g)(4): Recommended Alternative

Staff Recommends Alternative 1: No Action

- To date, industry plans communicated to the NRC have not indicated that there would be enough requests for package approvals, for transporting UF_6 enriched up to but less than 20.0 weight percent U-235, to conclude that rulemaking would be the most efficient or effective process to support package approvals.
- All alternatives are nearly cost neutral in terms of implementation;
- FRN Question
  - Is there additional information that can be shared to augment comments made by the public in June 2022 regarding the need for rulemaking to support licensing new or existing UF_6 transportation package designs?

Questions

Control Room Design Criterion of 10 CFR 50.67 and GDC-19

Elijah Dickson
Radiation Protection and Consequence Branch
NRR

Control Room Design Criterion of 10 CFR 50.67 and GDC-19: Summary of Regulatory Issue

- The history of fuel utilization for the current large light-water fleet has seen a gradual progression toward higher fuel discharge burnups and increased enrichments.

- In general, there has been enough margin in the facilities' design bases to accommodate the criterion even for power uprates of up to 120 percent of the originally licensed steady-state thermal power level.

- The NRC recognizes the challenges that licensees face to retain margin for operational flexibilities within their licensing basis and the small amount of margin to the control room design criterion itself.

- The NRC does not want to unnecessarily penalize licensees for seeking increased enrichments that may then result in margin reductions and thereby requiring licensees to perform potentially extensive analyses to demonstrate compliance without a commensurate increase in safety.

Control Room Design Criterion of 10 CFR 50.67 and GDC-19: Background – 1/2

- Objective: ensure the design of the control room and its habitability systems provide for a habitable environment allowing the operators to remain in the control room and not evacuate during an emergency. Ideally, the environment should be a “short-sleeved,” comfortable environment for the control room operators. Such an environment was perceived to facilitate operator response to normal and accident conditions.

- History: developed in the 1970s and amended in the 1990s, the criterion did not foresee how licensees currently operate their facilities and manage their fuel, consider fuel enrichments above 5 weight percent U-235, or maintain coherence with other regulations concerning the Commission's comprehensive radiation protection framework.

- Intent (Statements of Consideration for 10 CFR 50.67): “… the control room criterion does not imply that this would be an acceptable exposure during emergency conditions, or that other radiation protection standards of Part 20, including individual organ dose limits, might not apply. This criterion is provided only to assess the acceptability of design provisions for protecting control room operators under postulated DBA conditions. …”

Control Room Design Criterion of 10 CFR 50.67 and GDC-19: Background – 2/2

- Note: While the *design* criteria are computed in terms of “dose,” they are “figures of merit” used to characterize the minimum necessary design, fabrication, construction, testing, and performance of the requirements for SSCs that are important to safety. They do not represent actual occupational exposures received during normal and emergency conditions, which are primarily controlled by 10 CFR Part 20, “Standards for Protection Against Radiation.”

- Consider modifying the control *design* criteria to a higher, but still safe performance level; changes would not alter normal operational and emergency exposure limits controlled under 10 CFR Parts 20 and 10 CFR 50.47.

Control Room Design Criterion of 10 CFR 50.67 and GDC-19: Radiation Protection Regulatory Framework

- In **10 CFR Part 20**, the NRC applies these standards to all exposure situations—normal and emergency conditions—but also provides an explicit exemption for cases in which compliance would limit actions that may be necessary to protect health and safety.
- To provide reasonable assurance that adequate protective measures can and would be taken in a radiological emergency, the NRC has established emergency planning regulations in Appendix E, "Emergency Planning and Preparedness for Production and Utilization Facilities," to 10 CFR Part 50 and planning standards for nuclear power reactors in **10 CFR 50.47**, "Emergency plans."
- The Emergency Plans provides additional regulatory provisions to bear on the control of occupational exposures during emergencies. Paraphrased from Section **50.47.(b).(11)** provides the following:

  > "… Where the means for controlling radiological exposures shall include exposure guidelines consistent with EPA Emergency Worker and Lifesaving Activity Protective Action Guides."

- The guidelines for actions to protect valuable property is 10 rem where a lower dose is not practicable, the guidelines for actions to save a life or to protect large populations is 25 rem. These guidelines endorsed in Section **50.47.(b).(11)** is consistent with the position of **20.1001.(b).**

Control Room Design Criterion of 10 CFR 50.67 and GDC-19: Alternative 1

- *No Action - Maintain the current regulatory framework*
  - Continue to revise existing guidance with updated source terms when data become available and update transport models on an ad hoc basis as research and resources become available.
  - Plan to issue RG 1.183 Rev 2 in FY 2025.

Control Room Design Criterion of 10 CFR 50.67 and GDC-19: Alternative 2

- *Pursue Rulemaking to Amend the Control Room Design Criteria and Update the Current Regulatory Guidance Accordingly with Revised Assumptions and Models and Continue to Maintain Appropriate and Prudent Safety Margins*
  - Assess and identify a range of acceptable values based on sound regulatory and scientific recommendations.
  - Initiate new research and analyses for mechanistic transport models and re-baseline other several operational and human health assumptions
  - Plan to issue RG 1.183 Rev 2 in support of the amended control room design criteria.

Control Room Design Criterion of 10 CFR 50.67 and GDC-19: Alternative 3

- *Update the Current Regulatory Guidance with Revised Assumptions and Models and Continue to Maintain Appropriate and Prudent Safety Margins*
  - Initiate new research and analyses for mechanistic transport models and re-baseline other several operational and human health assumptions AND assess other mathematical methods, computational- and statistical approaches to reduce unnecessary conservatism and provide greater flexibility.
  - Plan to commence work on RG 1.183 Rev 3 based on new research and analyses soon after RG 1.183 Rev 2 is issued.

Control Room Design Criterion of 10 CFR 50.67 and GDC-19: Recommended Alternative

Staff recommends Alternative 2: Pursue rulemaking to amend the Control Room Design Criteria and update the current regulatory guidance accordingly with revised assumptions and models and continue to maintain appropriate and prudent safety margins

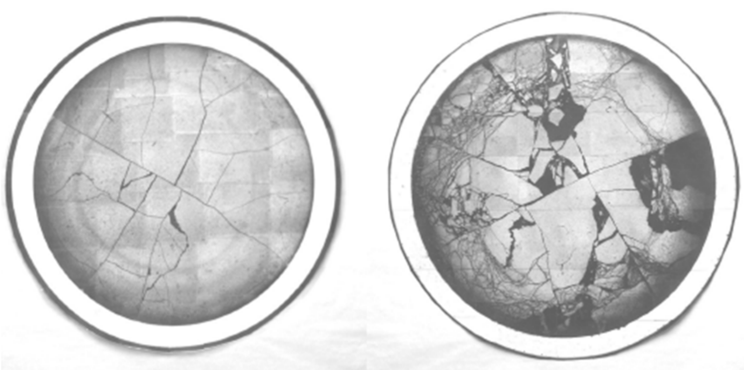
Questions

Fuel Dispersal

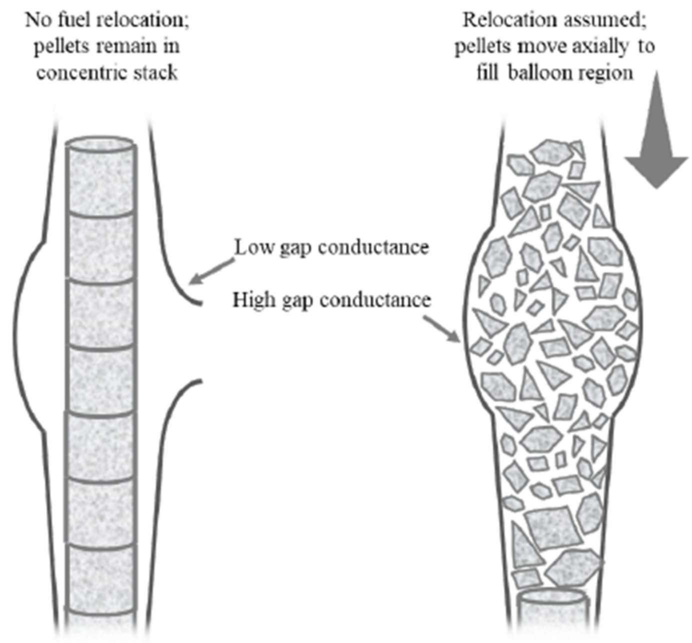
Joseph Messina
Ashley Smith
Nuclear Methods and Fuel Analysis
NRR

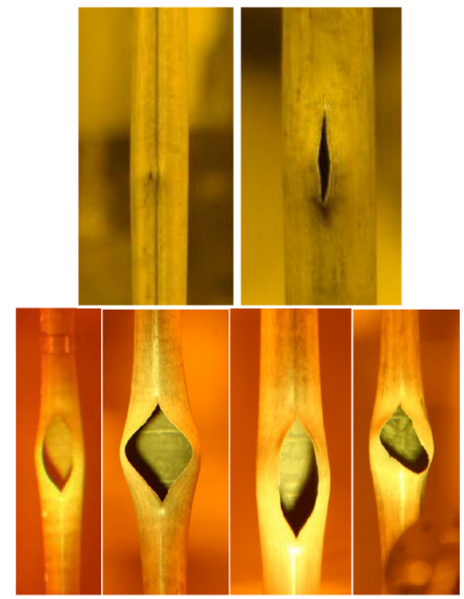
Fuel Fragmentation, Relocation, and Dispersal (FFRD)

- At HBU experiments have shown that the fuel can fragment during a LOCA
- Differences in pressure across the cladding can lead to cladding ballooning and burst
- The fragmented fuel can relocate axially into the balloon region of the fuel rod and if burst occurs, disperse into the RCS



Segment from NRC's ANL LOCA program at 55 GWd/MTU before and after testing





Burst openings from Studsvik LOCA tests (NUREG-2121)

FFRD: History

- 1974 – 10 CFR 50.46 criteria for LOCA's
- 1980 – FFRD Discovered
- 1984-1995 – GI-92, "Fuel Crumbling During LOCA"
- 2006 – FFRD testing showed gross fuel loss at high BU
- 2008 – RIL-0801
- 2012 – NUREG-2121
- 2015 – SECY-15-0148 – No imminent safety concern
- 2016 – Draft final rule for 50.46c
- 2021 – RIL-2021-13
- 2022 – SRM-SECY-21-0109 – Include FFRD in IE Rulemaking
- 2024 – Fuel Dispersal PIRT to be conducted

Fuel Dispersal: Background and Regulatory Issue

- The 50.46 acceptance criteria date to 1974 when FFRD were not known phenomena
- Acceptable approaches to demonstrate compliance with the regulations have ensured that catastrophic failure of the fuel rod structure and loss of fuel bundle configuration are precluded
  - Fuel dispersal would be a departure of precedent
- Fuel dispersal is not explicitly addressed within the current regulations

Fuel Dispersal: Alternatives

- The NRC staff have developed 5 licensing pathways that could be pursued as a part of IE rulemaking
- Alternatives should be seen as mutually inclusive (i.e., combinations of elements from multiple alternatives could be considered)
- NRC staff may consider other approaches based on public comments

Fuel Dispersal Alternative 1

- **<u>No action</u>**
- No major updates to regulatory framework
- Apply existing regulations for treatment of dispersal
- Licensees could show that rods susceptible to fine fragmentation would not rupture to demonstrate compliance
- Consideration of significant fuel dispersal without any major regulatory updates → challenges and regulatory uncertainty
  - Licensing pathways considering significant dispersal are discussed as part of other alternatives

Fuel Dispersal Alternative 2

- **50.46a-style modification of ECCS requirements**
- 50.46a was a draft final rule in 2010 that proposed to establish a transition break size (TBS), above which LOCAs can be analyzed with more realistic assumptions
- Best-estimate modeling and more realistic assumptions *may* help to demonstrate that no rods susceptible to dispersal would burst
- Increased margin for other ECCS requirements (e.g., PCT)
- May impact Increased Enrichment rulemaking schedule

Fuel Dispersal Alternative 3

- **Safety demonstration for post-FFRD consequences**
  - Criticality, coolability, dose, long-term cooling, etc. should be addressed like any other LOCA phenomena
- Guidance would be issued with the rule, which could be updated to include more specific guidance after more research is performed
  - Current state-of-knowledge may lead to conservative guidance, but research could be performed in the long term to relax guidance
- May impact Increased Enrichment rulemaking schedule

Fuel Dispersal Alternative 4

- **<u>Generic bounding assessment of dose and use risk insights for post-FFRD consequences</u>**
- Dose criterion for LOCA with fuel dispersal would be established
- Licensees would demonstrate ability to predict a fuel dispersal source term or be directed to use a fraction of the MHA-LOCA source term based on the amount of predicted fuel dispersal.
- Downstream effects of dispersal could be treated as beyond design basis consequences and addressed with risk insights
  - E.g., insights from operating experience and other regulatory requirements, programs, and industry initiatives
- May impact Increased Enrichment rulemaking schedule

Fuel Dispersal: Alternative 5

- **Probabilistic fracture mechanics to show that leaks in large pipes will be identified before failure, precluding the need to analyze LBLOCAs**
  - E.g., leak-before-break and xLPR
- Derived from industry initiatives
- Licensees could use LBB to demonstrate that RCS leaks could be detected and operator action taken before a pipe breaks for a postulated LBLOCA, thus precluding a LBLOCA and fuel failure.
- May impact Increased Enrichment rulemaking schedule

Fuel Dispersal: Recommended Alternative

<u>Staff Has No Recommendation at this time</u>

- The staff has determined that additional stakeholder input is required before finalizing a recommendation.
- 6 questions are posed to the public in the FRN regarding fuel dispersal to better understand stakeholder perspectives.
- The staff will review the stakeholder input on fuel dispersal to determine the path forward during the proposed rule.

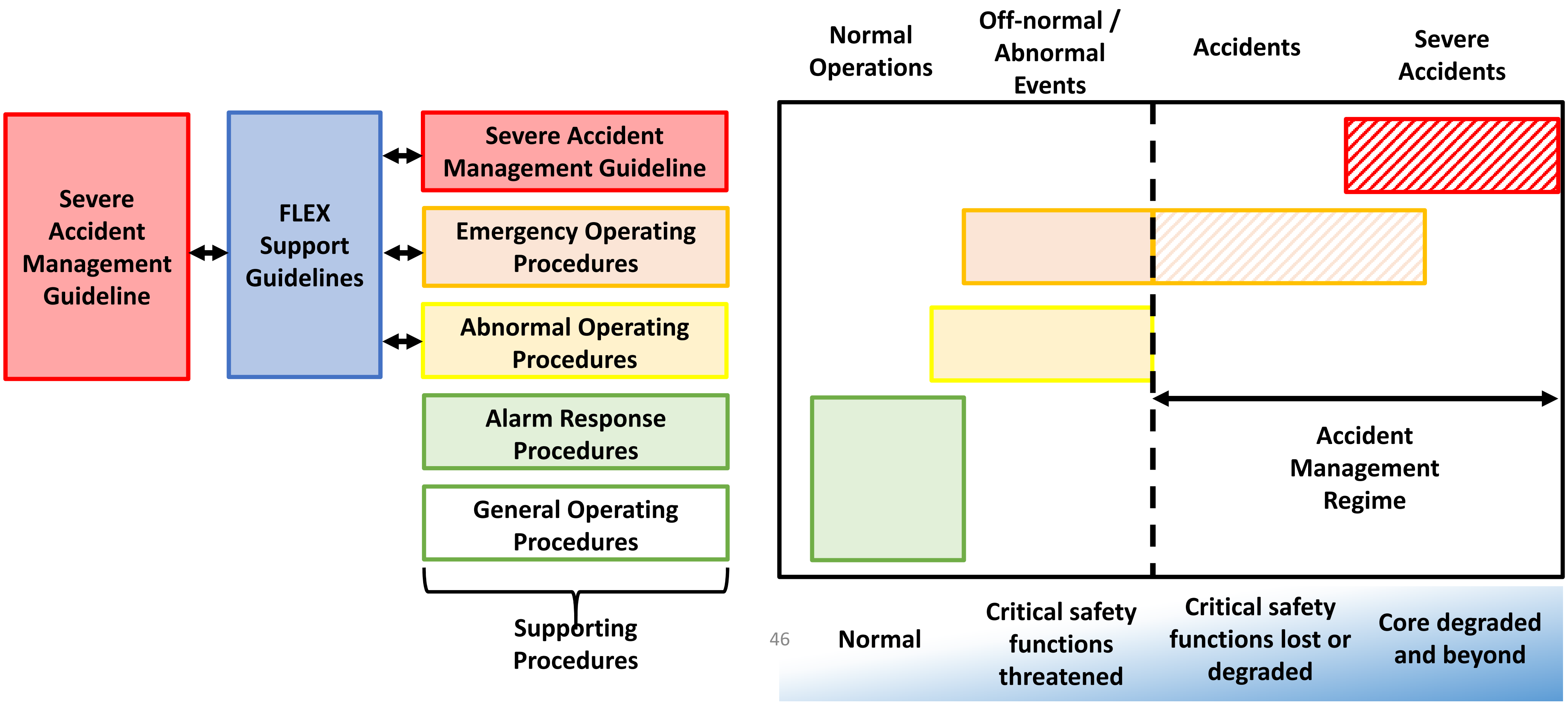
Fuel Dispersal: Alternatives

- Alternative 1: No action.
- Alternative 2: 50.46a-style modification of ECCS requirements.
- Alternative 3: Perform a safety demonstration for post-FFRD consequences.
- Alternative 4: Provide a generic bounding assessment of dose and use risk insights for post-FFRD consequences.
- Alternative 5: Use probabilistic fracture mechanics to show that leaks in large pipes will be identified before failure, precluding the need to analyze LBLOCAs.

Questions

Backup Slides

Control Room Design Criterion of 10 CFR 50.67 and GDC-19: Typical Role of Accident Management Guidelines



xLPR Background

- xLPR was co-developed by NRC/RES and EPRI to enable quantitative assessment of piping systems subject to active degradation mechanisms, such as primary water stress corrosion cracking, for compliance with GDC 4
- xLPR has not been used in any licensing applications to date
  - Used for confirmatory and internal calculations at the NRC
- Application of xLPR will need to be reviewed and approved by NRR
- Application specific guidance needed for FFRD Alternative 5

FFRD: Dispersal Estimates

- 2014 NRC RES nominal calculations predicted up to 207 kg of fuel dispersed at current BUs

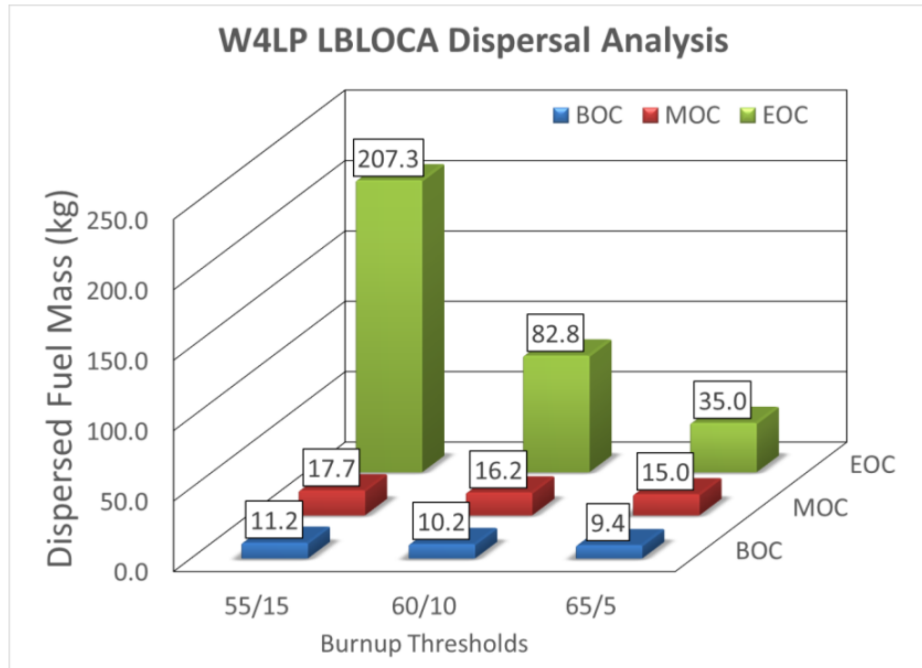
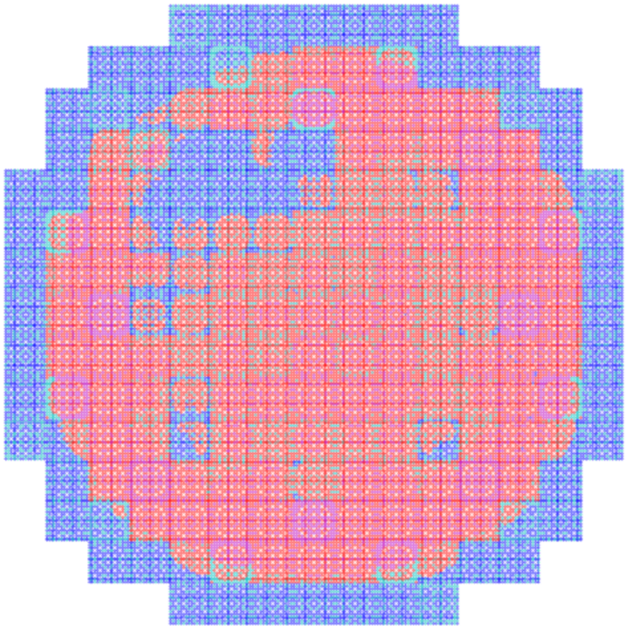


Figure 7.3-11 from "Report on Fuel Fragmentation, Relocation, and Dispersal," NEA/CSNI/R(2016)16, OECD Nuclear Energy Agency, October 2016.

FFRD: Dispersal Estimates

- 2023 RES calculations estimated 0.6% to 3.5% of the fuel in the core is dispersed at HBUs



Core map showing burst and non-burst rods for the base case. Red and magenta indicate burst IFBA and non-IFBA rods, respectively; blue and cyan indicate non-burst IFBA and non-IFBA rods, respectively

Parameter	Base Case	Chopped Cosine Power Shape	Top Peak Power Shape	Top Peak Power Shape (1 ECCS train)
Burst rods (%)				
IFBA	64	68	76	78
Non-IFBA	40	32	69	80
Total	58	58	74	78
Fuel dispersal (%)				
All fragment sizes	2.3	2.8	3.5	3.4
Fragments < 1 mm	1.1	1.9	2.1	2.1
Fragments < 1 mm above burst	0.6	1.3	1.1	1.1

Table II – Dispersal Estimates from "NRC's Methodology to Estimate Fuel Dispersal during a Large Break Loss of Coolant Accident," A. Bielen, J. Corson, and J. Staudemeier, NURETH, August 2023 (ML23116A214).

Fuel Dispersal: FRN Questions

1. Are there any other alternatives not described in Appendix F of the regulatory basis on FFRD that the NRC should consider? Are there elements of the alternatives presented or other alternatives that the NRC should consider? Please provide a basis for your response.

2. Stakeholders previously expressed concerns on the proposed § 50.46a rule when it was initially proposed in 2010. What concerns about § 50.46a (i.e., Alternative 2) exist in today's landscape? Please provide a basis for your response.

Fuel Dispersal: FRN Questions

3. Under Alternative 2, as currently proposed in the regulatory basis, the staff would apply the regulatory precedent under which fuel dispersal that would challenge current regulatory requirements would not be permitted under loss-of-coolant accident (LOCA) conditions. Would the increased flexibilities gained from best-estimate assumptions and methods employed during large-break LOCA analyses make this alternative reasonable? Please provide a basis for your response.

4. What changes to plant operations, fuel designs, or safety analysis tools and methods would be necessary under each proposed alternative? Please provide a basis for your response.

Fuel Dispersal: FRN Questions

5. Provide any information that would be relevant to more accurately estimate costs associated with each proposed alternative. Please provide a basis for your response.

6. What are the pros and cons of each alternative, including the degree to which each alternative is consistent with the principles of good regulation?