

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

October 25, 2023

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# Purpose

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- Provide information to facilitate stakeholders' comments on the Regulatory Basis on Increased Enrichment of Conventional and Accident Tolerant Fuel Designs for Light-Water Reactors.
- The NRC is not collecting comments on the regulatory basis during this meeting, rather we will describe how to submit comments.

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# Agenda

Time	Topic	Speaker
1:00-1:10	Welcome and Logistics	NRC
1:10-1:15	Opening Remarks	NRC
1:15-1:25	Background and Status	NRC
1:25-2:25	Regulatory Basis Overview with Question Sessions	NRC All
2:25-2:35	Break	
2:35-3:35	Regulatory Basis Overview with Question Sessions (Continued)	NRC All
3:35-3:50	Preparing and Submitting Comments	NRC
3:50-4:00	Closing Remarks	All

Topic times are estimated and, depending on the participation level, the meeting could adjourn earlier than scheduled. If there are concerns with a potential early meeting adjournment, please inform the point of contact for this meeting.

# Logistics

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- This meeting is being recorded
- During “Questions and Discussion” periods, please indicate your desire to speak by using the “Raise Hand” button in Teams (or press “\*5” if participating by phone)
- Once your name has been called by the facilitator, you will need to unmute yourself (press “\*6” if participating by phone)
- Chat feature is also enabled
- Presentation slides shown on the Microsoft Teams screen and in ADAMS at [ML23290A267](#)
- Phone attendees should email [Philip.Benavides@nrc.gov](mailto:Philip.Benavides@nrc.gov) for attendance record

# Opening Remarks

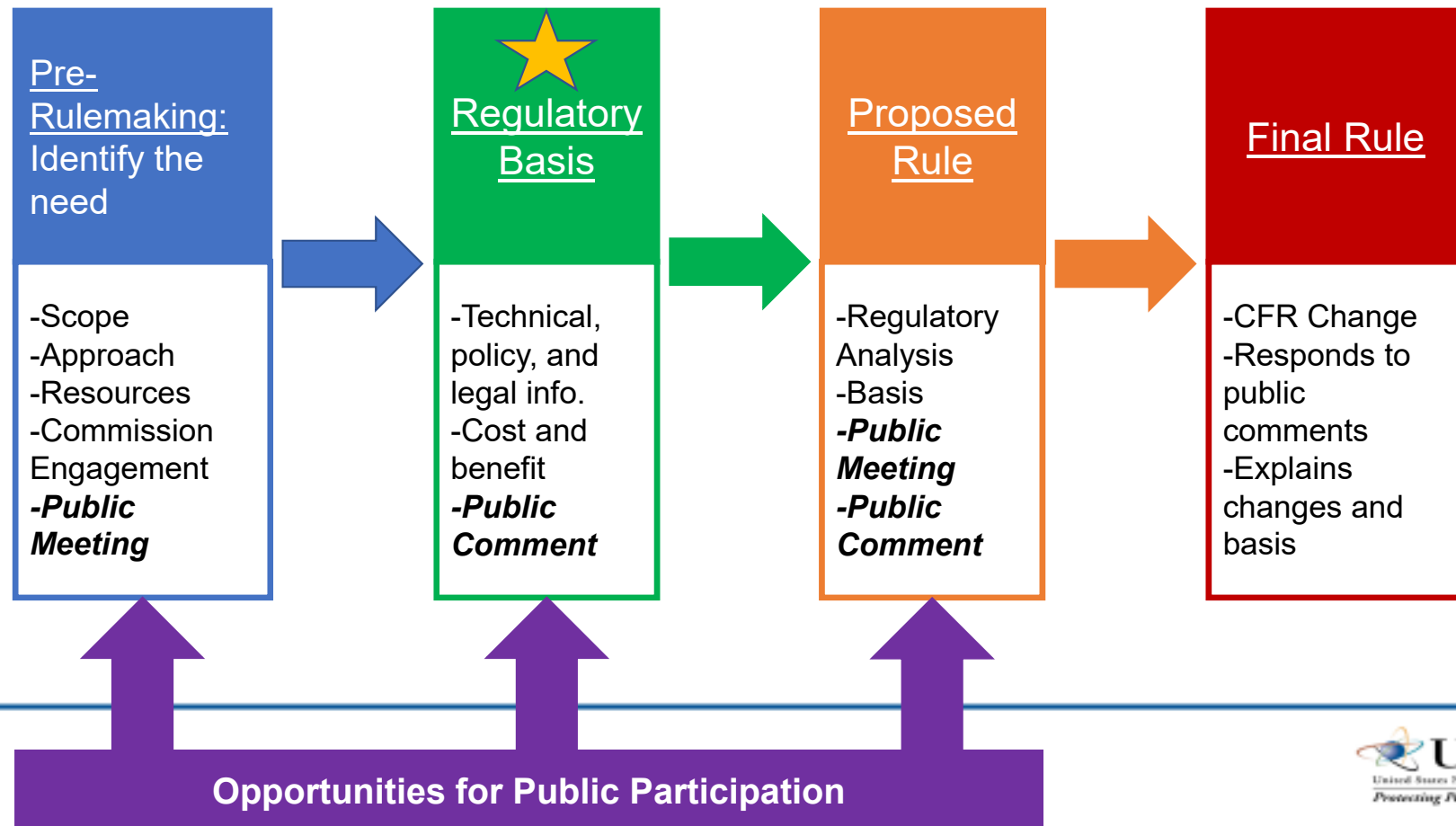
Andrea Kock  
Deputy Director  
NRR

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# Rulemaking Background and Status

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# Rulemaking Process



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# Issue Identification

- **Regulatory Issue:**

- Current licensing framework allows for the use of  $\leq 5$  weight percent uranium-235; however, technology developments may require numerous exemptions to utilize fuel enriched above 5 weight percent.

- **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.



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# SRM-SECY-21-0109 Overview

- SRM-SECY-21-0109 issued on 3/16/22, in response to SECY-21-0109.
  - The Commission has approved the staff's proposal to initiate a rulemaking to amend requirements for the use of light water reactor fuel containing uranium enriched to greater than 5.0 weight percent uranium-235.
  - Provisions to the rule should only apply to High-Assay Low Enriched Uranium (HALEU).
  - Fuel Fragmentation, Relocation, and Dispersal (FFRD) should be appropriately addressed.
  - Staff should take a risk-informed approach.
  - Staff should work with stakeholders to develop necessary regulatory guidance.
  - Staff should re-examine the proposed schedule to determine if key milestones can be achieved sooner by leveraging ongoing regulatory innovation efforts.

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# Status of Rulemaking Activity

- **The NRC staff issued a regulatory basis on September 8, 2023 (ADAMS Accession No. ML23032A504)**
  - 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
    - Fuel Fragmentation, Relocation and Dispersal: Alternatives offered with no recommendation at this time (pending on public input)
- **Stakeholder Involvement:**
  - Public Meeting
  - Comment Period until November 22, 2023

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# Regulatory Basis Topics

- **The regulatory basis describes the evaluated technical topics:**
  - Control Room Requirements (10 CFR 50.67 and GDC-19)
  - 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)
  - Fuel Dispersal

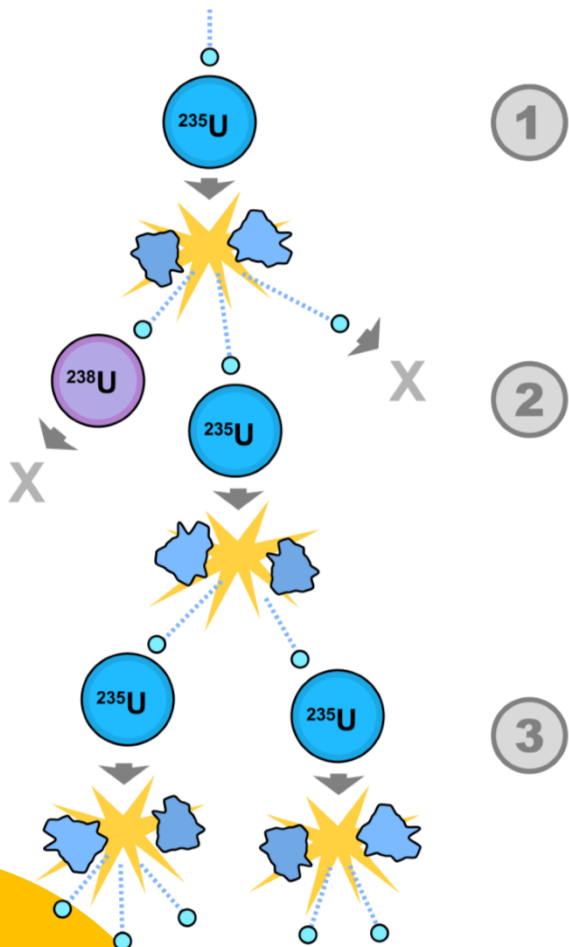
# Regulatory Basis Overview

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

- Final Rule issued in 1998
- Rule permits exemptions to 10 CFR 70.24 requirements
- Current rule limits application to enrichments of  $\leq 5\%$  weight Uranium-235
- Applicable at operating Part 50 and 52 licensees
- Utilizes k-effective acceptance criteria with required probability and confidence levels



# K-effective

- Defined as the Ratio of  
$$\frac{\text{Neutron Production}}{\text{Neutron Absorption} + \text{Neutron Leakage}}$$
- Describes neutron population change from one fission generation to the next
- $K < 1$ , Subcritical Chain Reaction  
 $K = 1$ , Critical Chain Reaction  
 $K > 1$ , Supercritical Chain Reaction

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## 10 CFR 50.68: Alternatives

1. *No Action* - New and Spent Fuel Criticality Safety is determined in accordance with 10 CFR 70.24 or an approved plant-specific exemption
2. *Rulemaking* - Increase Enrichment limit in 10 CFR 50.68(b)(7) to < 20.0% wt U-235
3. *Rulemaking* - Remove Specific Enrichment Limit and replace with Tech Spec Design Feature Limits (**recommended**)

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## 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

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# 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 wt % 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).

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## 10 CFR 51.51: 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 with Table S-3 data as bounding
2. *Rulemaking* - Pursue the necessary environmental analysis to justify continued use of Table S-3 for increased enrichment and then pursue rulemaking to modify Table S-3 (**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

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## 10 CFR 51.52: Alternatives

1. *No Action* - Maintain current regulatory framework by assessing environmental impacts from transportation of fresh fuel enriched above 5% U-235 per 10 CFR 51.52(b) on a case-by-case site-specific basis.
2. *Rulemaking* - Pursue the necessary environmental analysis to justify continued use of Table S-4 for increased enrichment and then pursue rulemaking to modify Table S-4 (**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

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# Packaging Requirements of 10 CFR 71.55: Summary of Regulatory Issue

## Current Regulations

- § 71.55(b) applicants evaluate a single package, optimally moderated and reflected
  - § 71.55(g) Provides an exception for package containing UF<sub>6</sub>
  - § 71.55(g)(4) Specifies that enrichment cannot exceed 5 weight percent U-235

## Regulatory History

- Proposed rule (§ 71.55(g)) issued 67 FR 21390, April 30, 2002, Final Rule issued 69 FR 3698, January 26, 2004
- Codified NRC longstanding practice to provide an exception to § 71.55(b)

## External Issues related to enrichment limit of 5 weight percent

- ANSI N14.1, ISO 7195, and DOT limit enrichment in cylinders larger than 8 inches in diameter to 5 weight percent U-235
- IAEA Standards in SSR-6 limit exception to 5 weight percent U-235 for international transportation.

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## 10 CFR 71.55: Certificate of Compliance (CoC) Options

### **Options for seeking approval by CoC**

- Evaluate UF<sub>6</sub> packages with optimum moderation
  - current package design
  - redesigned package
- Request an exemption to § 71.55(b)
- Request approval under § 71.55(c) for an exception to the optimum moderation requirement in § 71.55(b). (Requires special design feature and adm. controls.)

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## 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



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# 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<sub>6</sub> 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<sub>6</sub> transportation package designs?

# Questions

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**Break**

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# **Regulatory Basis Overview (Continued)**

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## 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.

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# 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.

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# 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.

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# 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.



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# 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.

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# 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.

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# 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

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## FRN Question 1

Would the numerical selection of the control room design criteria be better aligned with regulations designed to limit occupational exposures during emergency conditions (e.g., §§ 20.1206, “Planned special exposures,” and 50.54(x)) or regulations designed to limit annual occupational radiation exposures during normal operations (e.g., § 20.1201, “Occupational dose limits for adults,” specifically the requirements in § 20.1201 (a)(1)(i))? Please provide a basis for your response.

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## FRN Question 2

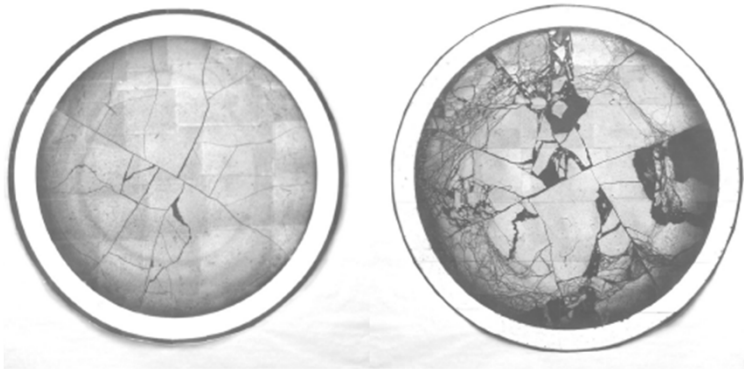
Would a graded, risk-informed method, to demonstrate compliance with a range of acceptable control room design criterion values instead of a single selected value such as the current 5 rem (50 millisievert(mSv)) total effective dose equivalent (TEDE) provide the necessary flexibilities for current and future nuclear technologies up to but less than 20.0 weight percent U-235 enrichment? Please provide a basis for your response.

# Questions

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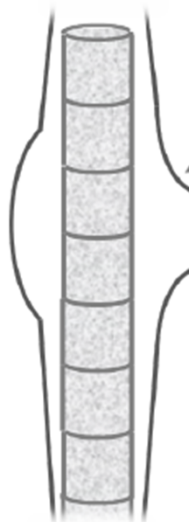
# Fuel Fragmentation, Relocation, and Dispersal (FFRD)

- At high burnup experiments have shown that the fuel can fragment during a loss-of-coolant accident (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 reactor coolant system

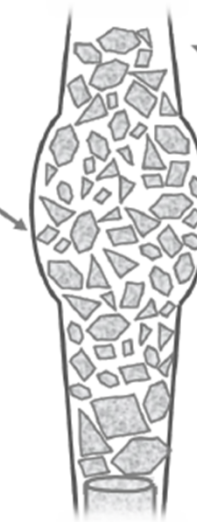


Segment from NRC's ANL LOCA program at 55 GWd/MTU before and after testing

No fuel relocation;  
pellets remain in  
concentric stack

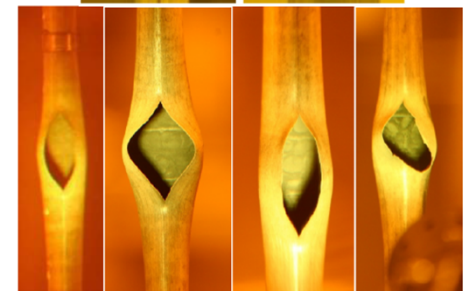
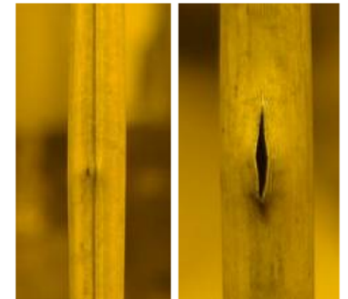


Relocation assumed;  
pellets move axially to  
fill balloon region



Low gap conductance

High gap conductance



Burst openings from Studsvik LOCA tests (NUREG-2121)

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# 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



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# Fuel Dispersal: Alternatives

- The NRC staff have developed 5 licensing pathways that could be pursued as a part of Increased Enrichment 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

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# Fuel Dispersal Alternative 1

- **No action**
- 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 regulatory updates → challenges and regulatory uncertainty
  - Licensing pathways considering significant dispersal are discussed as part of other alternatives

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## 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 emergency core cooling system requirements (e.g., peak cladding temperature)
- May impact Increased Enrichment rulemaking schedule

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## 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

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## Fuel Dispersal Alternative 4

- **Generic bounding assessment of dose and use risk insights for post-FFRD consequences**
- 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 maximum hypothetical accident-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

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## Fuel Dispersal: Alternative 5

- **Probabilistic fracture mechanics to show that leaks in large pipes will be identified before failure, precluding the need to analyze large break LOCAs (LBLOCAs)**
  - E.g., leak-before-break (LBB) and Extremely Low Probability of Rupture (xLPR) code
- Derived from industry initiatives
- Licensees could use LBB to demonstrate that reactor coolant system 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

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# Fuel Dispersal: Recommended Alternative

## **Staff Has No Recommendation at this time**

- 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.

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## 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.



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## 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.

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## 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.

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## 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?

# Questions

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# Regulatory Basis Summary

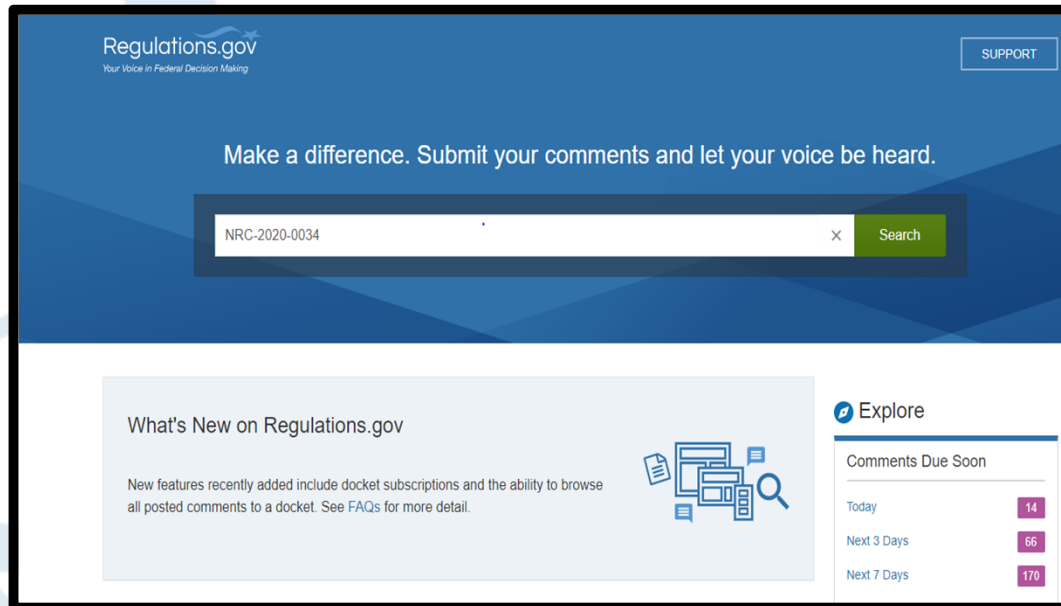
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- Sufficient regulatory basis to proceed with rulemaking for:
  - Control Room Design Criterion of 10 CFR 50.67 & GDC-19
  - Criticality Accident Requirements of 10 CFR 50.68
  - Environmental Requirements of 10 CFR 51.51 & 51.52
- No rulemaking for Packaging Requirements of 10 CFR 71.55
- Additional stakeholder input is required before finalizing a recommendation for Fuel Fragmentation, Relocation and Dispersal.

# Preparing and Submitting Comments

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# Where to Find Information



The screenshot shows the Regulations.gov homepage. At the top left is the logo "Regulations.gov" with the tagline "Your Voice in Federal Decision Making". At the top right is a "SUPPORT" button. Below the header is a large blue banner with the text "Make a difference. Submit your comments and let your voice be heard." In the center of the banner is a search bar containing the text "NRC-2020-0034" and a green "Search" button. Below the banner, the page is divided into two columns. The left column is titled "What's New on Regulations.gov" and contains text about new features: "New features recently added include docket subscriptions and the ability to browse all posted comments to a docket. See FAQs for more detail." The right column is titled "Explore" and contains a section "Comments Due Soon" with a table showing the number of comments due in different timeframes.

Comments Due Soon	
Today	14
Next 3 Days	66
Next 7 Days	170

Go to <https://www.regulations.gov>  
and search for docket ID **NRC-2020-0034**

# Submitting a comment

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- **Ways You Can Submit Comments:**

- **Regulations.gov:** [comment form](#) for the regulatory basis on docket NRC–2020–0034

*or*

- **Email:** [Rulemaking.Comments@nrc.gov](mailto:Rulemaking.Comments@nrc.gov)

*or*

- **Fax:** Secretary, U.S. Nuclear Regulatory Commission at 301–415–1101

*or*

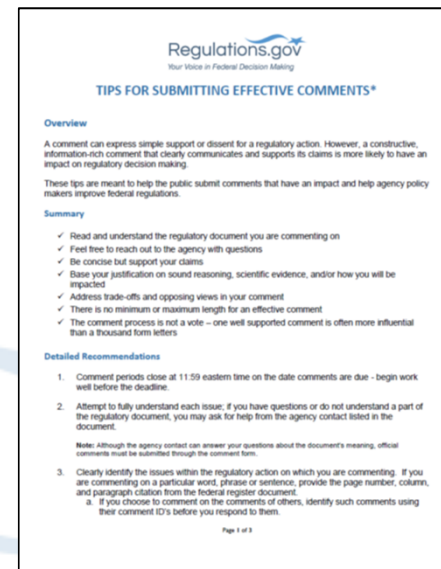
- **Mail:** Secretary, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, ATTN:  
Rulemakings and Adjudications Staff

- **Frequently Asked Questions (FAQs)** on commenting are available at:  
<https://www.regulations.gov/faq>



## Commenter's Checklist on Regulations.gov

- Available from [Regulations.gov](https://downloads.regulations.gov/FS-2018-0053-0007/content.pdf) at:  
<https://downloads.regulations.gov/FS-2018-0053-0007/content.pdf>
- This information is also available from the page for submitting comments on the proposed rule:  
<https://www.regulations.gov/comment/NRC-2020-0034-0005>



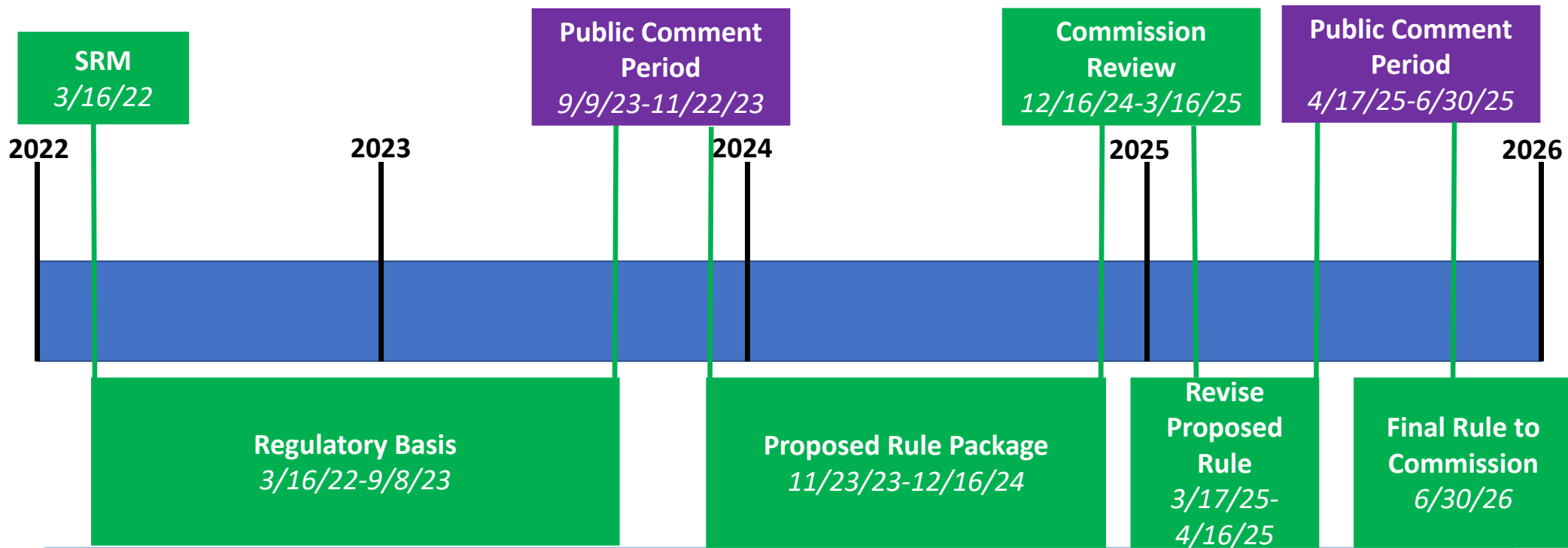
# Next Steps

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- Public comment period closes on November 22, 2023
- Consider public comments
- Develop proposed rule
- Proposed rule due to the Commission: December 2024\*
  - Public comment period after Commission approval
  - Public meeting(s) during the public comment period
- Final rule to the Commission: June 2026\*

*\*Dates listed are estimates only, and thus are subject to change.*

# Current Schedule



*Note: Dates listed are estimates only, and thus are subject to change.*

# Contacts

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# How did we do?

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- The public meeting feedback form can be accessed on the meeting details page:

<https://www.nrc.gov/pmns/mtg?do=details&Code=20231108>

# Closing Remarks

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