



# BWR Fuel Performance Update

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Framatome/NRC Fuel Performance Meeting

September 14, 2021

## AGENDA

- Objectives
- Framatome BWR Fuel Operating Experience
  - Fuel Performance Summary
  - Status of Product Implementation
    - Advanced Debris Filters
    - ATRIUM 11
    - Z4B BQ Channels
- Status of Framatome BWR Fuel Failures and Investigations
  - Fuel Reliability Statistics
  - Status of Recent Fuel Failures Discharged
- Poolside Surveillance Results and Plans
  - Recent BWR Poolside Surveillance and Hot Cell Campaigns
  - Upcoming BWR Poolside Surveillance Campaigns
- EATF and Other Development Summary
- Summary / Conclusions



## Objectives

- Summarize key aspects of current BWR fuel product features
- Provide a status update of the overall performance of Framatome's BWR designs
- Provide an updated status of ATRIUM 11 fuel and Z4B BQ ( $\beta$ -quench) channel programs
- Provide an overview of BWR fuel examinations and results of recent surveillance campaigns
- Provide an overview of anticipated BWR fuel examinations
- Provide an overview of the current EATF projects

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## Fuel Reliability Status | Plants with Leaker Free Cores in Operations (United States)

United States	
PWR	100%
BWR	100%
TOTAL	100%

(As of August 2021)

**Framatome fuel has operated defect free since June 2020**

# Framatome BWR Fuel Performance Summary

## United States

All BWRs with Framatome fuel in-core operating defect free

Advanced ATRIUM 11 fuel product continues to perform well

- Reliability features: reduced fuel rod duty with 11x11 array, Cr-doped fuel, debris-resistant spacers, 3rd Generation FUELGUARD (3GFG) and Z4B BQ fuel channels
- 12 ATRIUM 11 lead assemblies in United States BWRs reached discharge burnup after 6 years in spring 2021
- 3 full ATRIUM 11 reloads currently in operation in US reactors

Majority of debris filters in operation are advanced FUELGUARD generations

- All continuing reload supply will utilize the 3GFG from 2021 and beyond

NRC approval achieved for use of Z4B material in channel reloads

- Z4B BQ fuel channels from industrialized process completed 6 years operation in 2020
- Full reloads of Z4B BQ channels currently being delivered

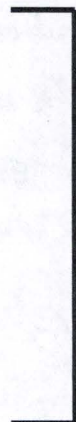
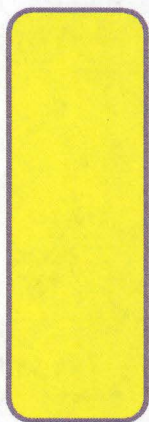
First BWR additive manufactured components inserted into a US reactor in spring 2021

EATF coated BWR LTRs inserted into a United States reactor in spring 2021

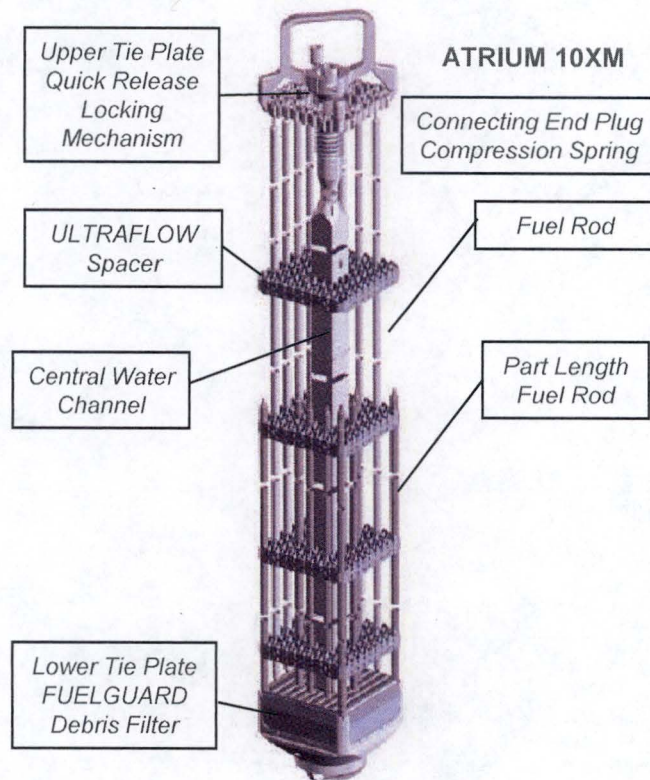


# Framatome BWR Fuel Performance Summary

## United States



# ATRIUM Product Platform





# Summary of Current ATRIUM Product Line | Primary Design Differences

# Global ATRIUM Product Line Supply



# Global ATRIUM Irradiation Experience

## Domestic ATRIUM Product Supply



## BWR Fuel Product Line | Advanced Debris Filters

## Domestic Debris Filter Supply



## Debris Filter Performance (Global)

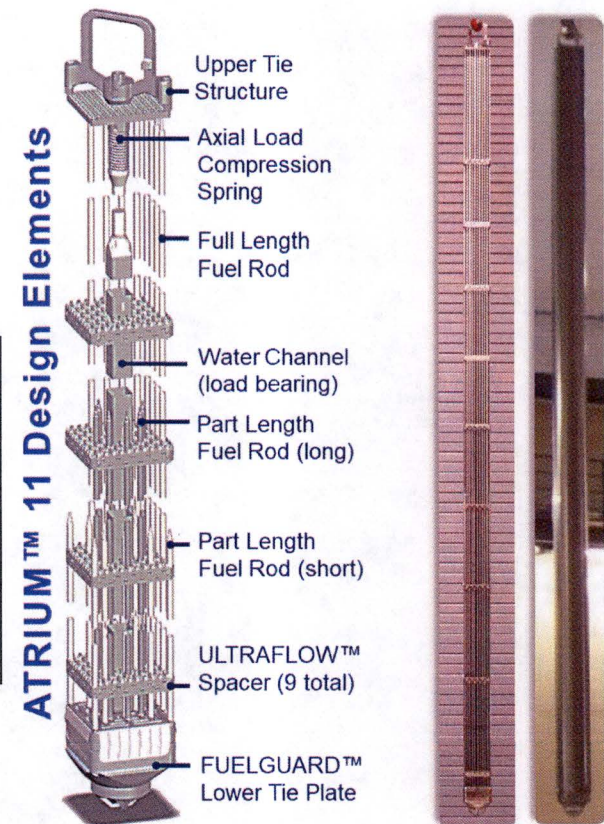
Advancements in debris filter technology have proven benefits to fuel reliability

## BWR Fuel Product Line | ATRIUM 11

- The ATRIUM 11 is the latest evolution of Framatome's ATRIUM product line for BWRs
  - 11x11 fuel rod array to enhance enrichment utilization efficiency and increase thermal-mechanical margins
  - Vaned ULTRAFLOW spacer grids and increased fuel rod surface area to improve dryout performance
  - Debris protection at inlet with 3GFG filter, entrapment resistant spacer grids, and top entry grid lattice

**The ATRIUM 11 is the most efficient BWR fuel assembly in reload operation**

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## Fuel Design Materials | ATRIUM 11

## Global ATRIUM 11 Reloads



## BWR Fuel Product Line – Advanced Channel Materials

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## Framatome BWR Fuel Failures (10 years) | United States

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## Recent Framatome BWR Failures





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## Recent Framatome BWR Failures

# Advanced Inspection Technology

\* Human hairs range from 2 to 6 mils in diameter

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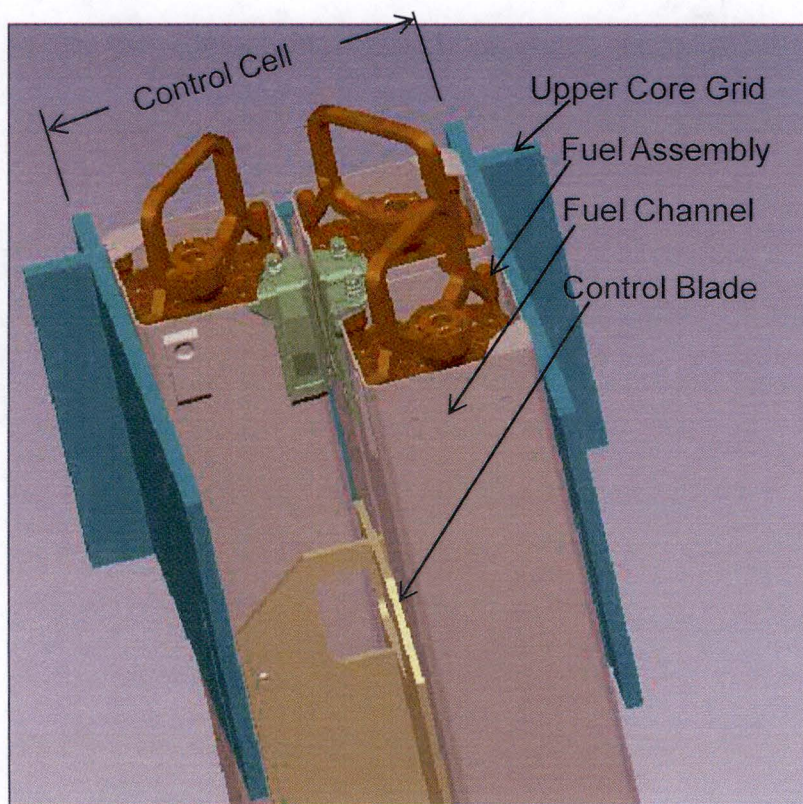
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# Domestic BWR Poolside Surveillances

# Channel Poolside Inspections

## Channel Poolside Inspections



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# Channel Performance Assessment

# Channel Performance Assessment

# Fuel Rod Hot Cell Program



## Hot Cell Examination - Status

# Preliminary Results

## Preliminary Results



# LaSalle Hot Cell Schedule

# Anticipated BWR Fuel Surveillance Campaigns

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## BWR EATF

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# Additive Manufactured Component Irradiation Program

## Summary/Conclusions

- Framatome BWR fuel continues to perform well
- Framatome BWR customers are actively transitioning to advanced debris filter technology which are more effective solutions for in-reactor debris mitigation
- Framatome is committed to proactively monitor for and resolve conditions adverse to fuel reliability consistent with customer support
- Framatome is successfully implementing next generation products incorporating proven and effective design features
- Framatome's active Post Irradiation Examination program continues to validate fuel performance



**Framatome is committed to proactively addressing conditions adverse to fuel reliability and supporting our customers with leaker free performance**

## Acronyms/Nomenclature

• 3GFG	3 <sup>rd</sup> Generation FUELGUARD	• EOL	End of Life
• AFC	Advanced Fuel Channel	• EU	European Union
• AM	Additive Manufacturing	• FC	Fuel Channel
• BWR	Boiling Water Reactor	• F-SECT	Frequency Scanning Eddy Current Technique
• BQ	Beta Quench	• FTS	Failed-to-Settle
• CER	Ceramography	• GAD	Gadolinia
• CNL	Canadian Nuclear Laboratories	• H	Hydrogen
• Cr	Chromium	• HC	Hot Cell
• DMLM	Direct Metal Laser Melting	• HVEMS	Hot Vacuum Extraction Mass Spectroscopy
• EATF	Enhanced Accident Tolerant Fuel	• ID	Inside Diameter or Identification
• ECT	Eddy Current Testing	• IFG	Improved FUELGUARD
• EDS	Energy Dispersion Spectroscopy	• LTA	Lead Test Assembly
• EFID	Effective Full Power Days	• LTR	Lead Test Rod
• EOC	End of Cycle	• MET	Metallography



## Acronyms/Nomenclature

• NRC	Nuclear Regulatory Commission	• STS	Slow-to-Settle
• OD	Outside Diameter	• TVA	Tennessee Valley Authority
• ORNL	Oak Ridge National Laboratory	• UO <sub>2</sub>	Uranium Oxide
• PCI	Pellet-Clad Interaction	• US	United States
• PIE	Post Irradiation Examination	• USW	Upset Shape Welding
• PLFR	Part Length Fuel Rod	• Z4B	Zircaloy-4 BWR
• PPM	Parts Per Million	• ZN	Zinc
• PST	Power Suppression Testing	• ZrO <sub>2</sub>	Zirconium Oxide
• PWR	Pressurized Water Reactor	• Zry-2	Zircaloy-2
• RXA	Recrystallized Annealed		
• SEM	Scanning Electron Microscope		
• SFC	Standard Fuel Channel		
• SFG	Standard FUELGUARD		
• SRA	Stress-Relief Annealed		

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