

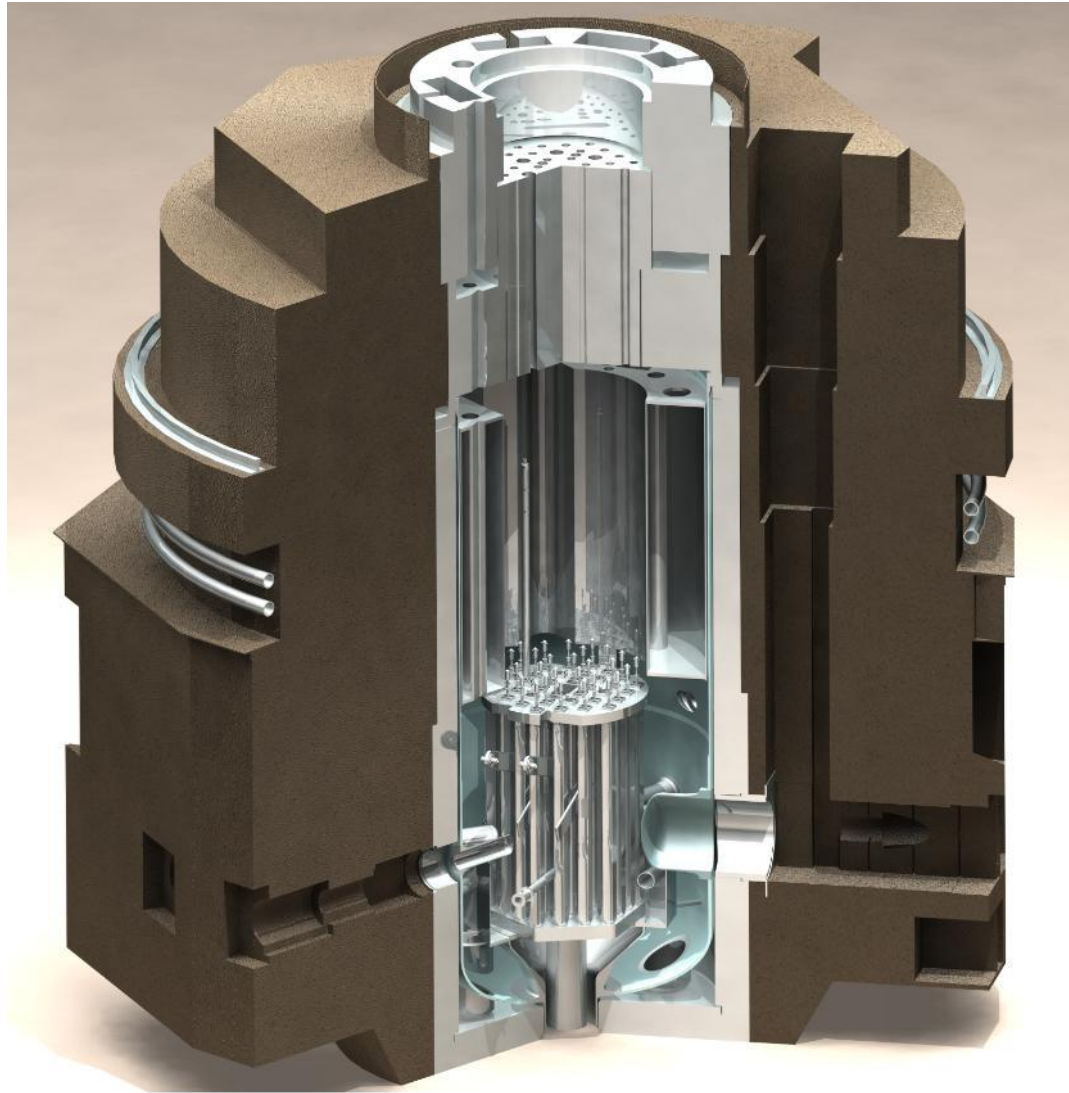
From Fuel Failure to Robust Engagement

Investigation, Redesign, and Validation of the NBSR Fuel Element Head

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- NBSR and RP Description
- Failure History
- Failure Hypotheses
- Investigation Plan
- Key Findings
- Corrective Redesign
- Conclusions

NBSR Design Overview



- HEU fuel (93% ^{235}U) – $\text{U}_3\text{O}_8 + \text{Al}$
 - 350 g ^{235}U /fuel element
 - 34 plates: 11" $\times$ 2.5" $\times$ 0.02"
 - Heavy water coolant (D_2O)
- 30 Fuel Elements
 - ~38-day fuel cycle at 20 MW
 - 4 fresh elements per cycle (usually) with a management scheme to shuffle other elements in the core
 - ~960 g of ^{235}U consumed per cycle
 - 7 or 8 cycles per element depending on where it is loaded initially
- Axially split-core
 - BTs and CNS(s) are at the thermal neutron flux trap elevation
 - BT fluxes $\sim 1.5 \times 10^{14}$ n/cm²-s

The Story in One Slide

A fuel failure exposed a latching vulnerability
The response evolved from detecting it to designing it out.

Accident

An unlatched fuel element led to loss of cooling and cladding failure.

problem revealed

Response

Procedures, latch checks, and visual verification reduced the chance of missing the condition.

risk administratively managed

Redesign

FEH version two adds geometry that makes engagement more robust to degraded interface conditions.

issue mitigated

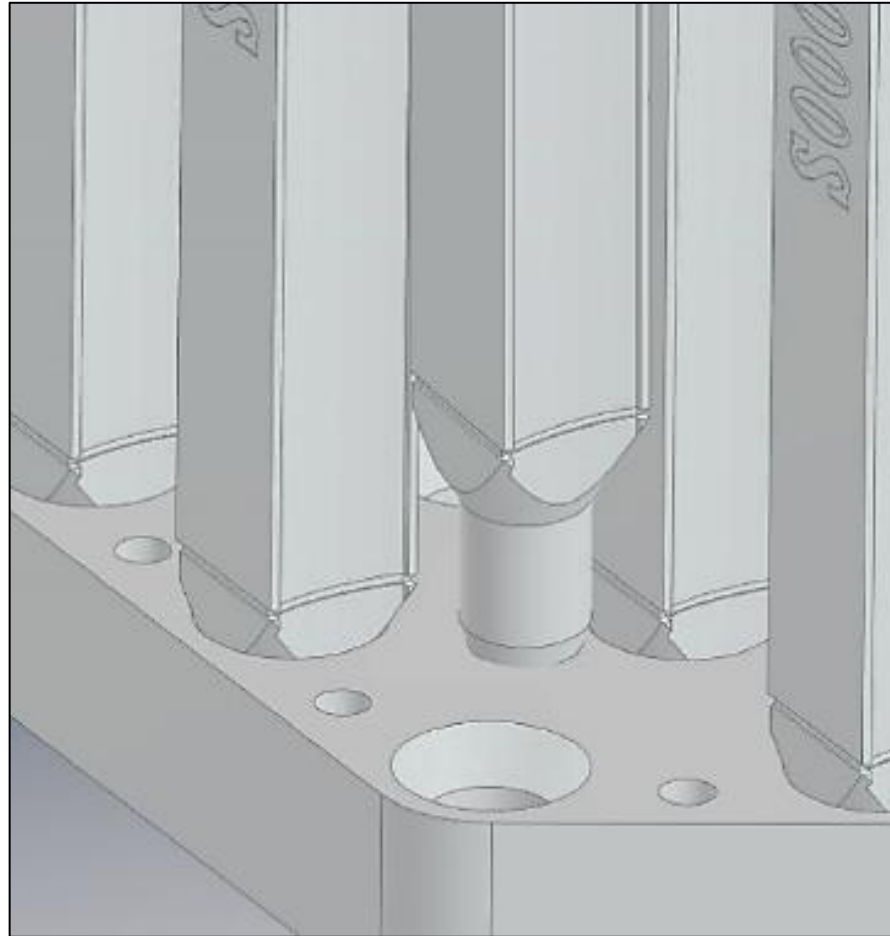
The Accident: Unlatched Fuel Element

Root Condition

Fuel element head Locking component did not achieve secure engagement with the Upper Grid Plate groove

Mechanism

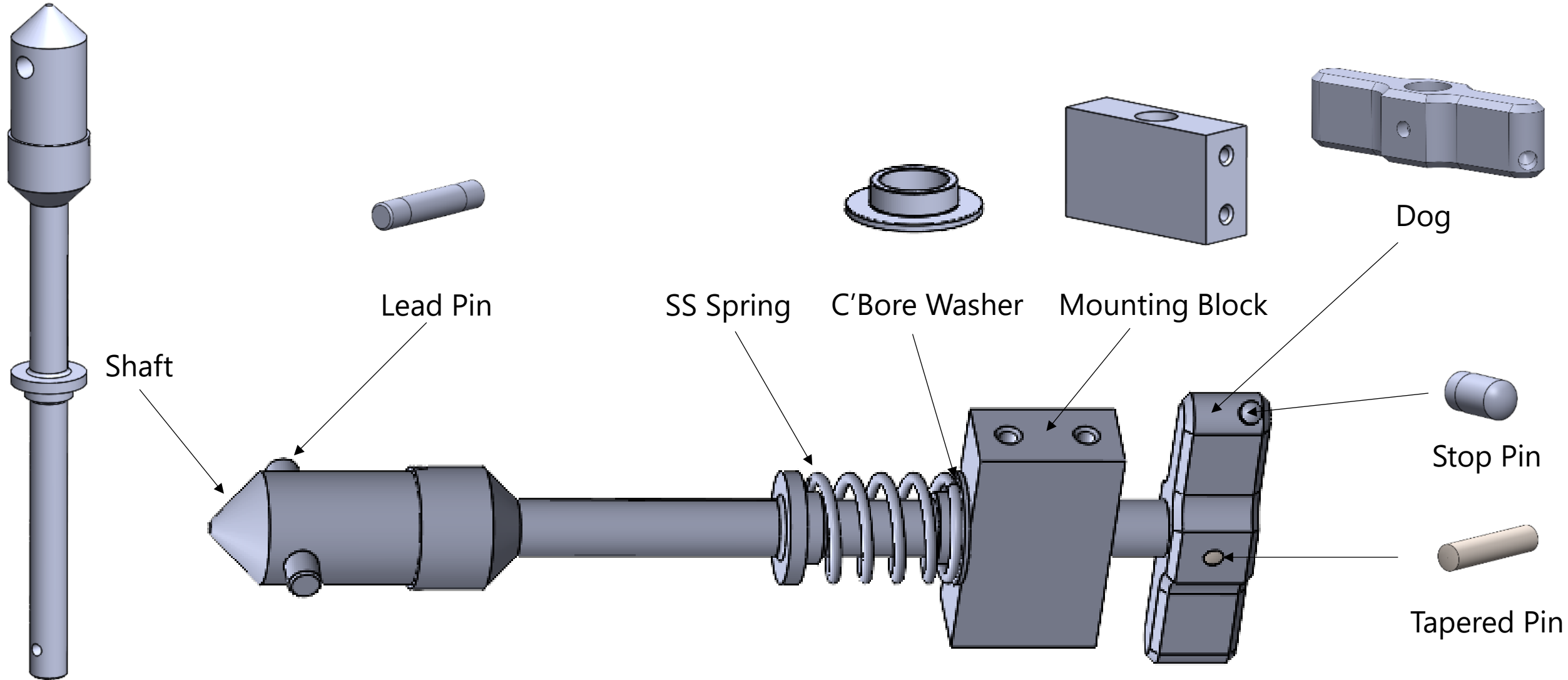
Coolant flow forces displaced the unlatched element - not a structural failure



Consequence

Loss of adequate cooling; fuel damage; fission-product release

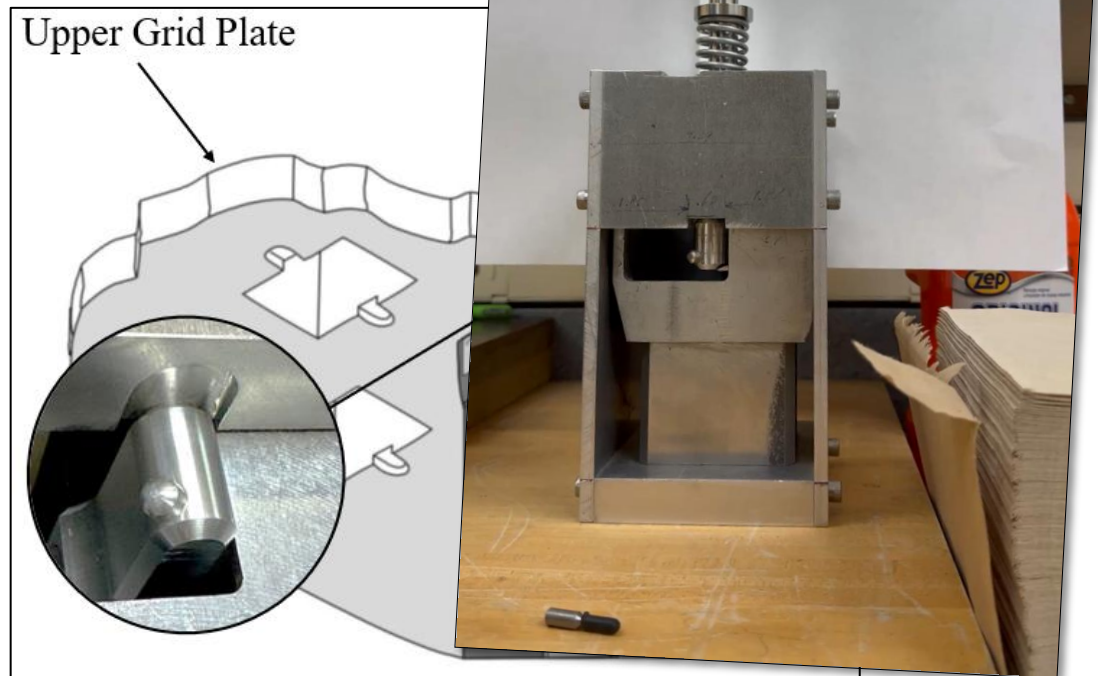
The Fuel Element Head (FEH)



Robustness Was the Issue

FEH Function

The Fuel Element Head latches each Upper Grid Plate (UGP) via the locking dog in the groove in the UGP.



✓ **Structural strength**

Adequate — not the concern

⚠ **Engagement sensitivity**

Locking-dog engagement in shallow or worn UGP grooves

⚠ **Back-rotation risk**

Spring relaxation could allow shaft to back-rotate, disengaging dogs

Immediate Actions Reduced Recurrence Risk



Revised Procedures

Fuel-handling steps tightened;
qualification and proficiency
requirements strengthened



Redundant Latch Checks

Multiple independent
verifications required before
element is considered secured



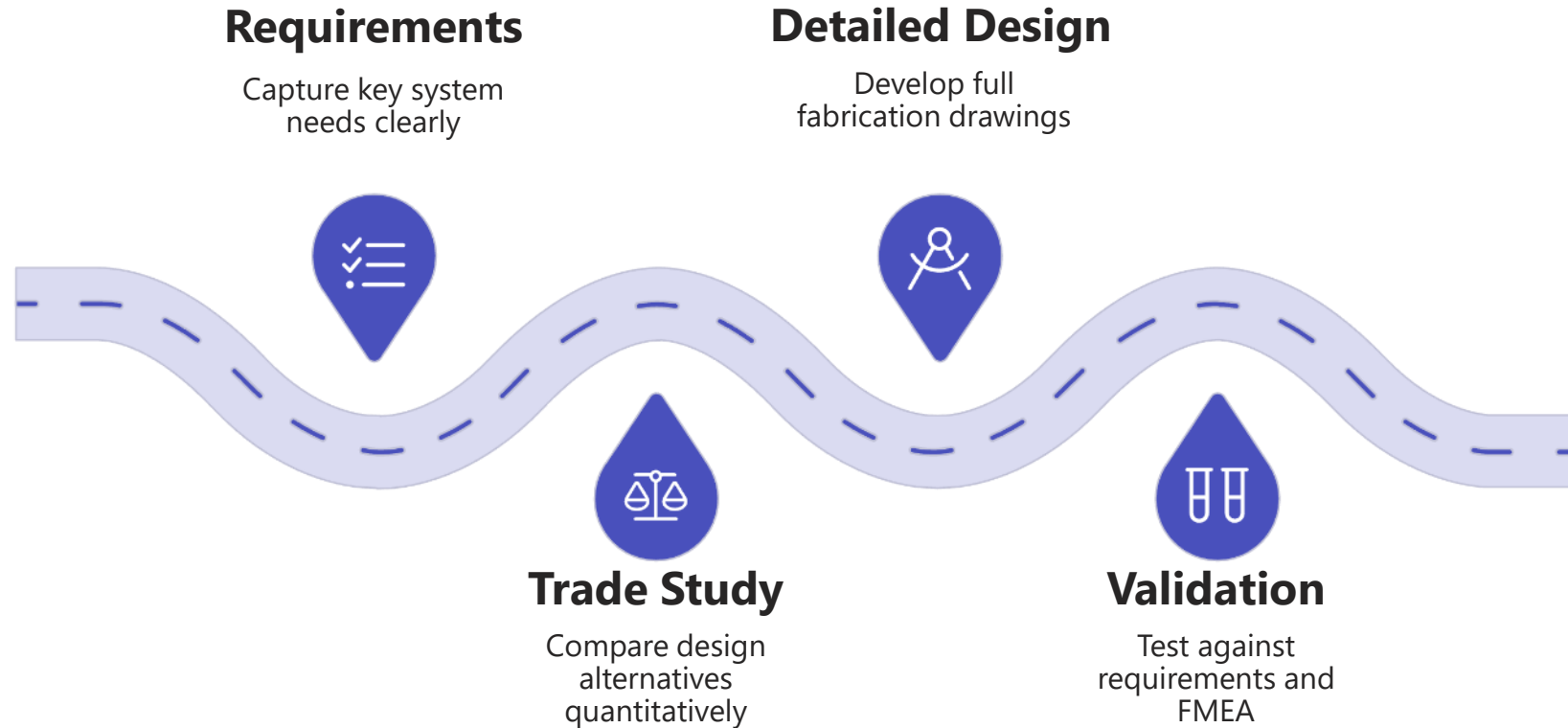
Visual Verification

Camera-based inspection
introduced; index-plate and tool
controls improved



These measures strengthened detection and reduced recurrence risk.

The next engineering question: **Could the FEH itself be made less sensitive to shallow engagement and unintended back-rotation?**



Key Requirements

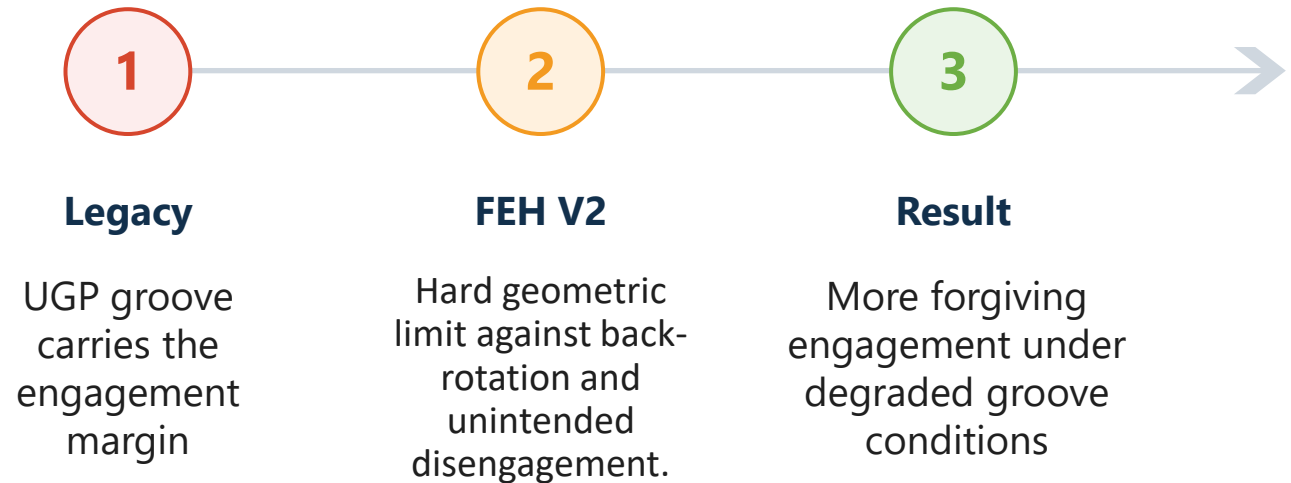
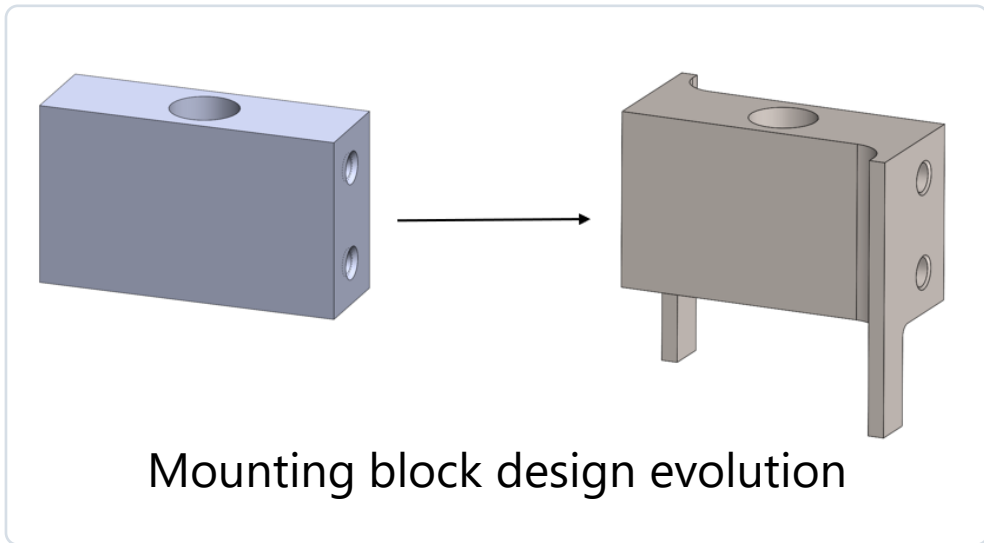
- Secure Latch
- Preserve Structural and Environmental Margins
- Clear Feedback For Operators
- Compatibility to Core Components

Preserved Interfaces

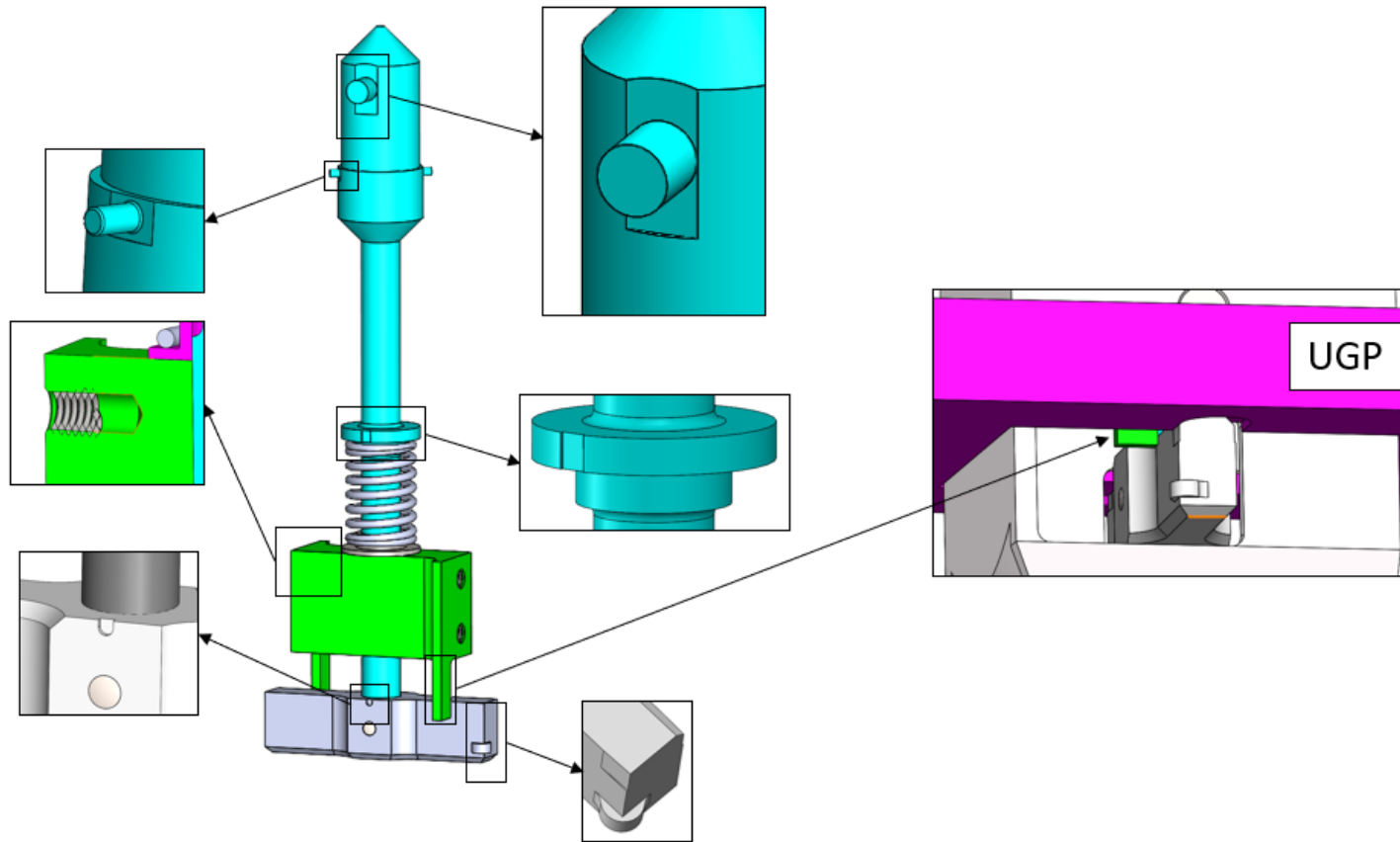
- Fuel element geometry - unchanged
- Upper Grid Plate - no modification
- Handling tools - unchanged
- Operating sequence - unchanged

The Key Move: Shift the Locking Margin Into the FEH

Rather than relying only on inspections and the UGP groove, FEH V2 adds a local stop that resists unintended back-rotation and shifts the wear.



Assembly Improvements



Titanium Shaft

One-piece; Integrates lead and spring-pin features; reduces small parts.

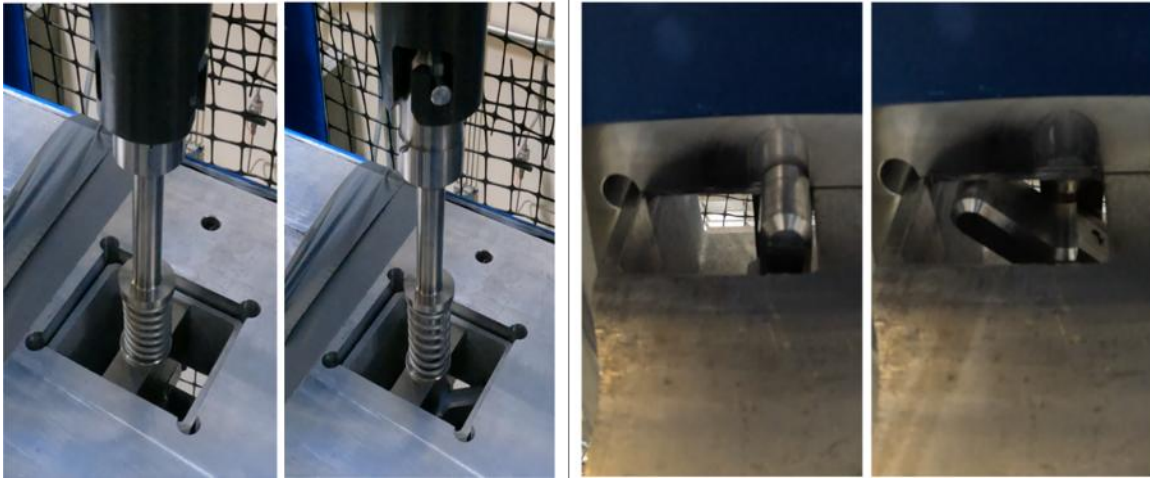
Integrated Locking Dog

Stop function built in; improved engagement geometry

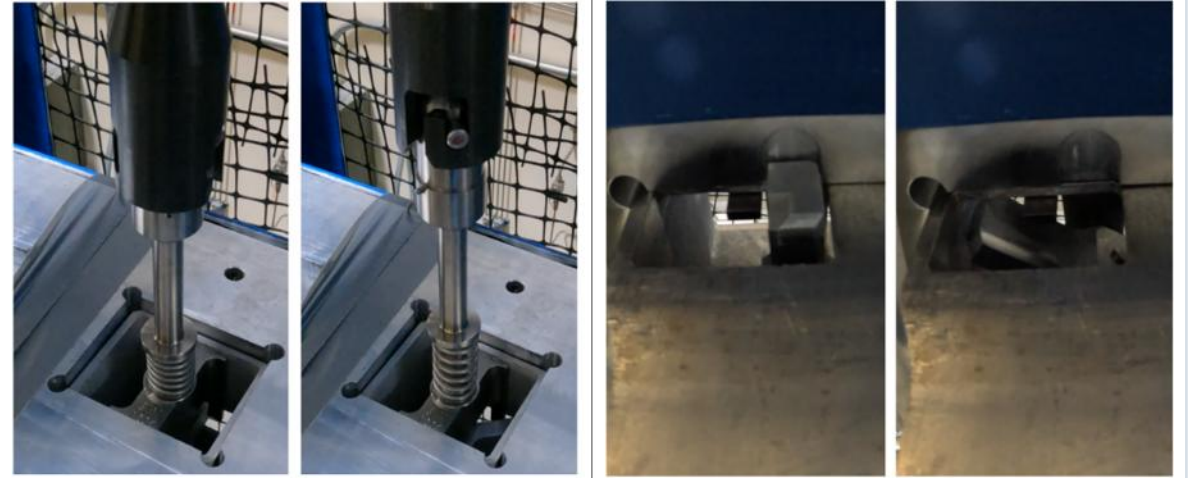
Additional Improvements

Orientation grooves reduce assembly error; locking helicoils improve screw retention

Normal Operation



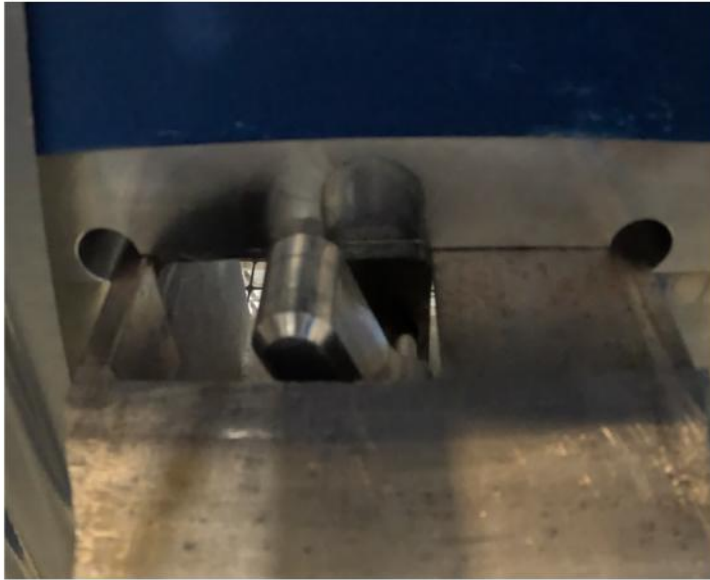
Legacy FEH



FEH V2

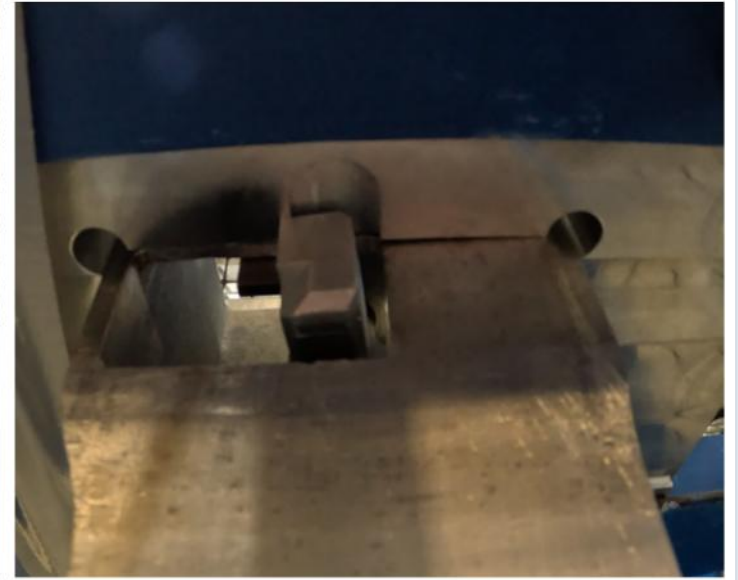
Both completed repeated latching / unlatching cycles successfully using the same handling tools.

Off-Normal Operation; Bump/Push



Legacy FEH

loss of secure latching observed



FEH V2

remained latched in all evaluated cases

From Workarounds to Robust Engagement

FEH V2 is a low-risk, implementation-ready improvement in fuel-element retention reliability.

1

Head-on mitigation

Mounting-block stop and improved dog geometry reduce sensitivity to shallow / worn UGP grooves. Back rotation consequence eliminated.

2

No new burden

Fuel geometry, UGP, tools, external envelope, and operating sequence remain unchanged.

3

Validated improvement

FEH V2 operated normally and remained latched during off-normal bump / push testing.

