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A Study of a Helium-3 Injection System at TREAT

Update and Design

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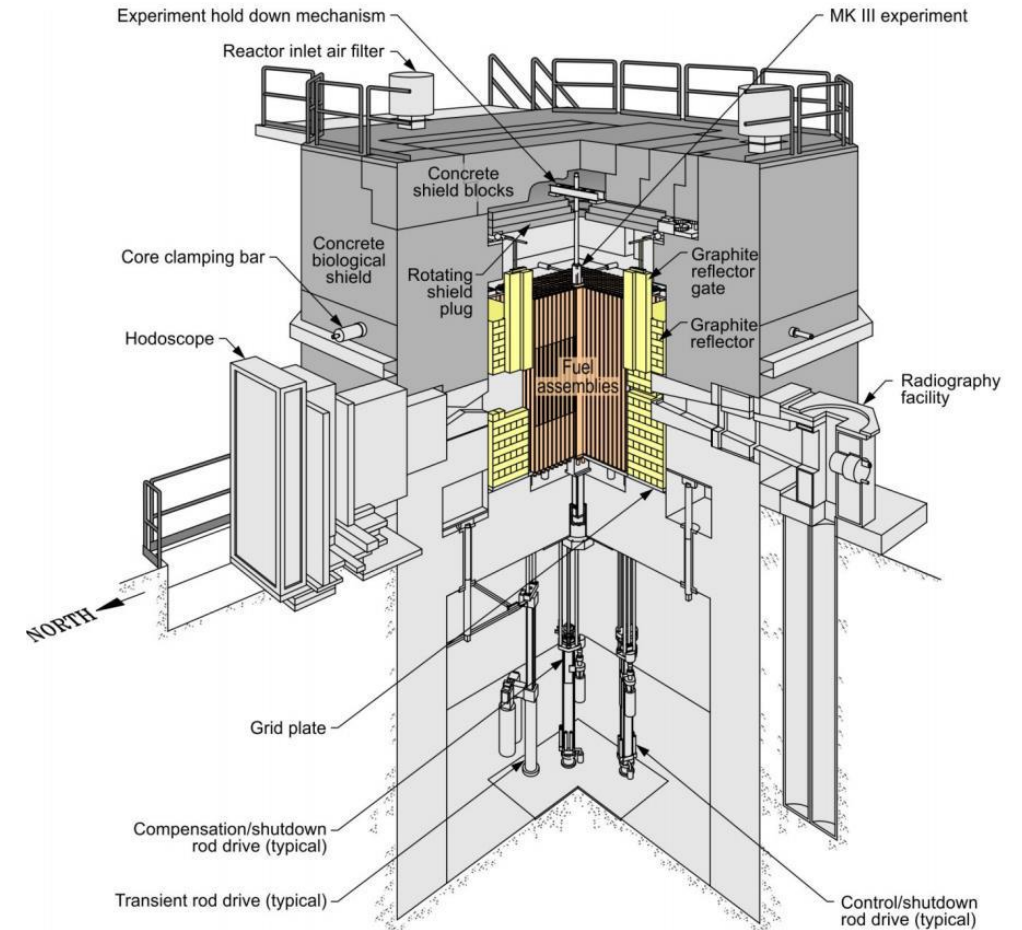
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Outline

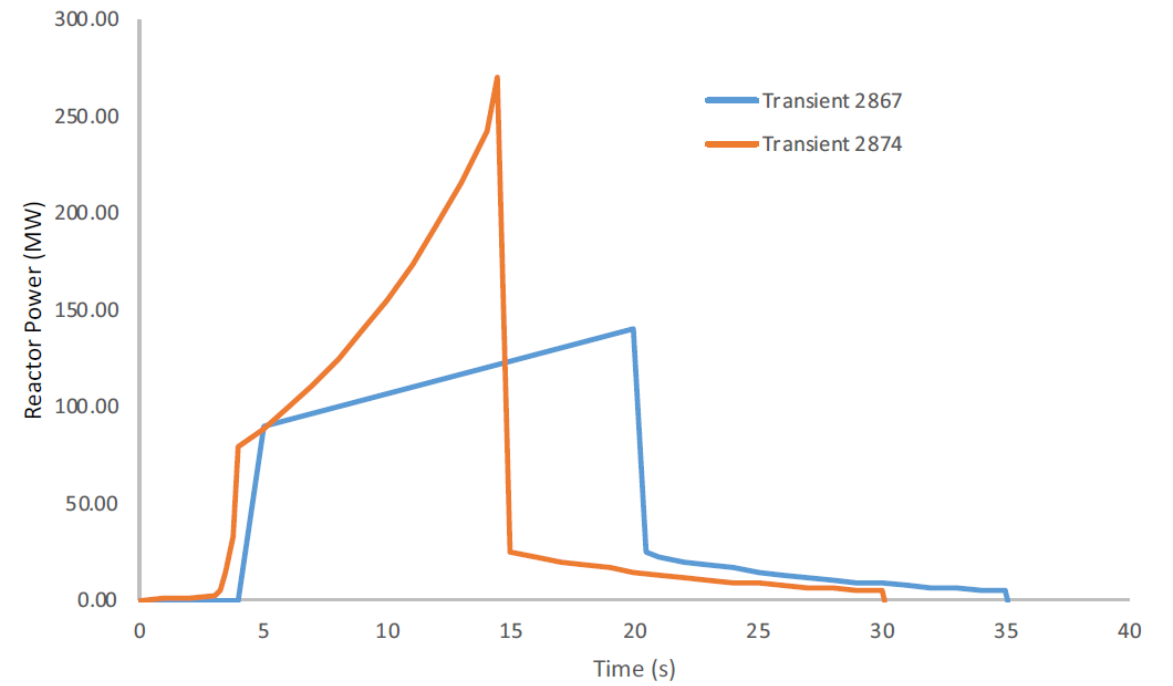
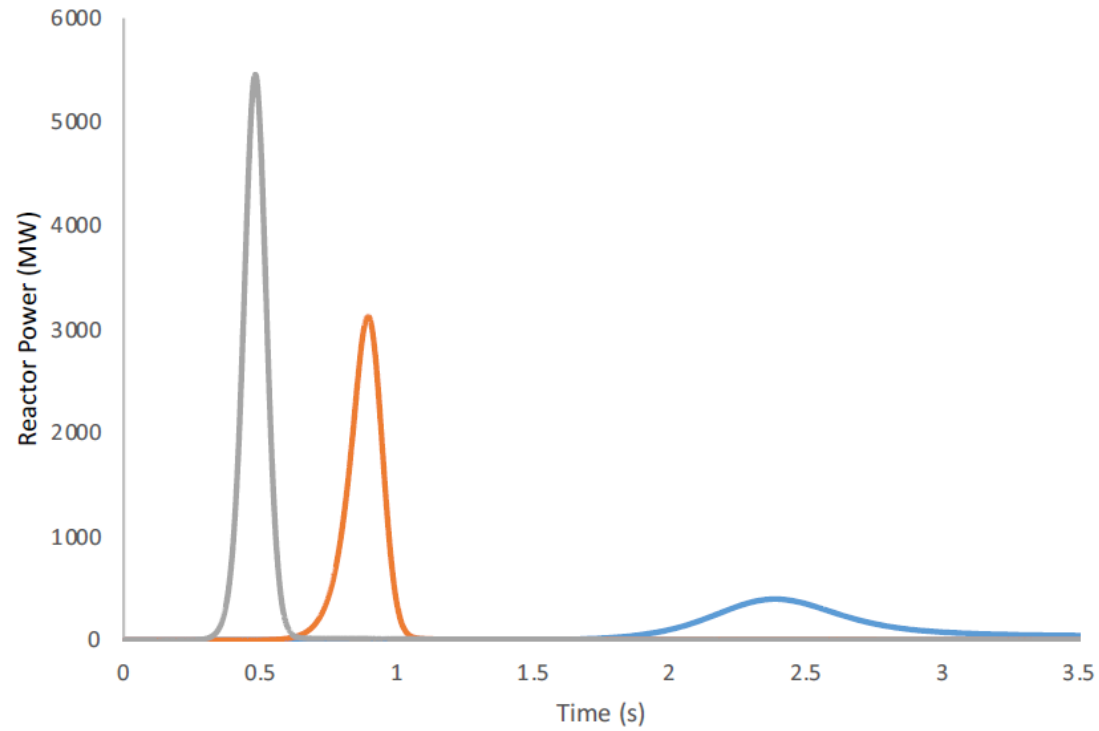
- What is the Transient Reactor Test Facility (TREAT)
 - Summary
 - Capabilities
 - Reactor Control
- Reactivity Initiated Accidents (RIAs)
- TREAT capabilities for RIA testing
 - 2019 Study of how to meet RIA fuel testing needs
- Current design of the Helium-3 Negative Reactivity Injection (HENRI) system
 - In core modules
 - Recovery system
 - Operation
 - Analyzed capability added to TREAT

Transient Reactor Test Facility (TREAT) Overview

- Air-cooled, graphite moderated reactor
- 10,000:1 atoms C to atoms U
- Steady state of 120 kW
- Minimum Period of 0.023 s
- Peak Power of 18,000 MW
- Peak Energy of 2,100 MJ
- Performs transients:
 - Temperature Limited
 - Clipped
 - Shaped
- Tests nuclear fuels in extreme transient environments (crash testing of nuclear fuels)



TREAT Overview



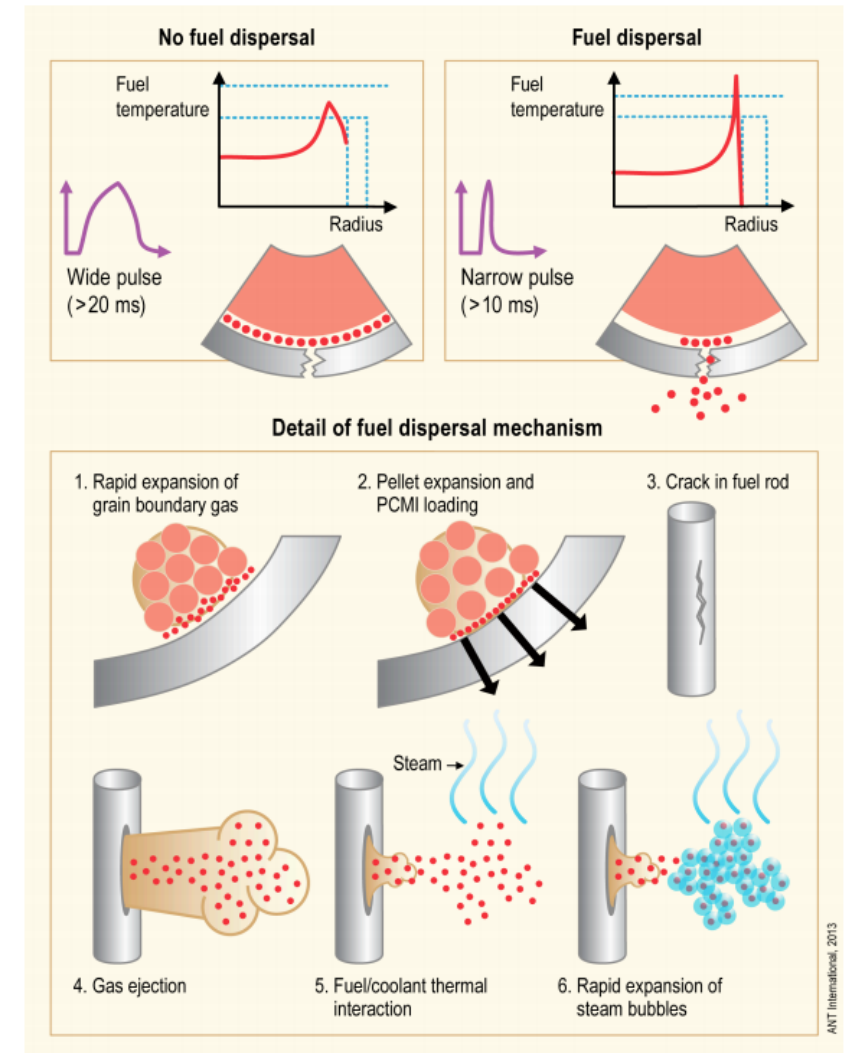
TREAT Control Overview

- 20 Control Rods
 - 8 control/shutdown rods
 - 4 compensation shutdown rods
 - 8 transient rods
- Control/shutdown rods bring the TREAT core critical and maintain it at power.
- Transient rods are positioned based on desired power profile.
- Compensation/shutdown rods are typically removed from the core during reactor operation

Type	Nominal Reactivity Worth (Core 1469) [3]	Effective Length [2]	Velocity	
			Reactivity Insertion [3]	Reactivity Removal (Clip/Scram) [3]
Control/Shutdown Rods	0.088 $\Delta k/k$	58 in.	20 in./min.	300 in./sec.
Compensation/Shutdown Rods	0.069 $\Delta k/k$	58 in.	20 in./min.	300 in./sec.
Transient Rods	0.085 $\Delta k/k$	40 in.	Adjustable (0-140 in./sec.)	140 in./sec

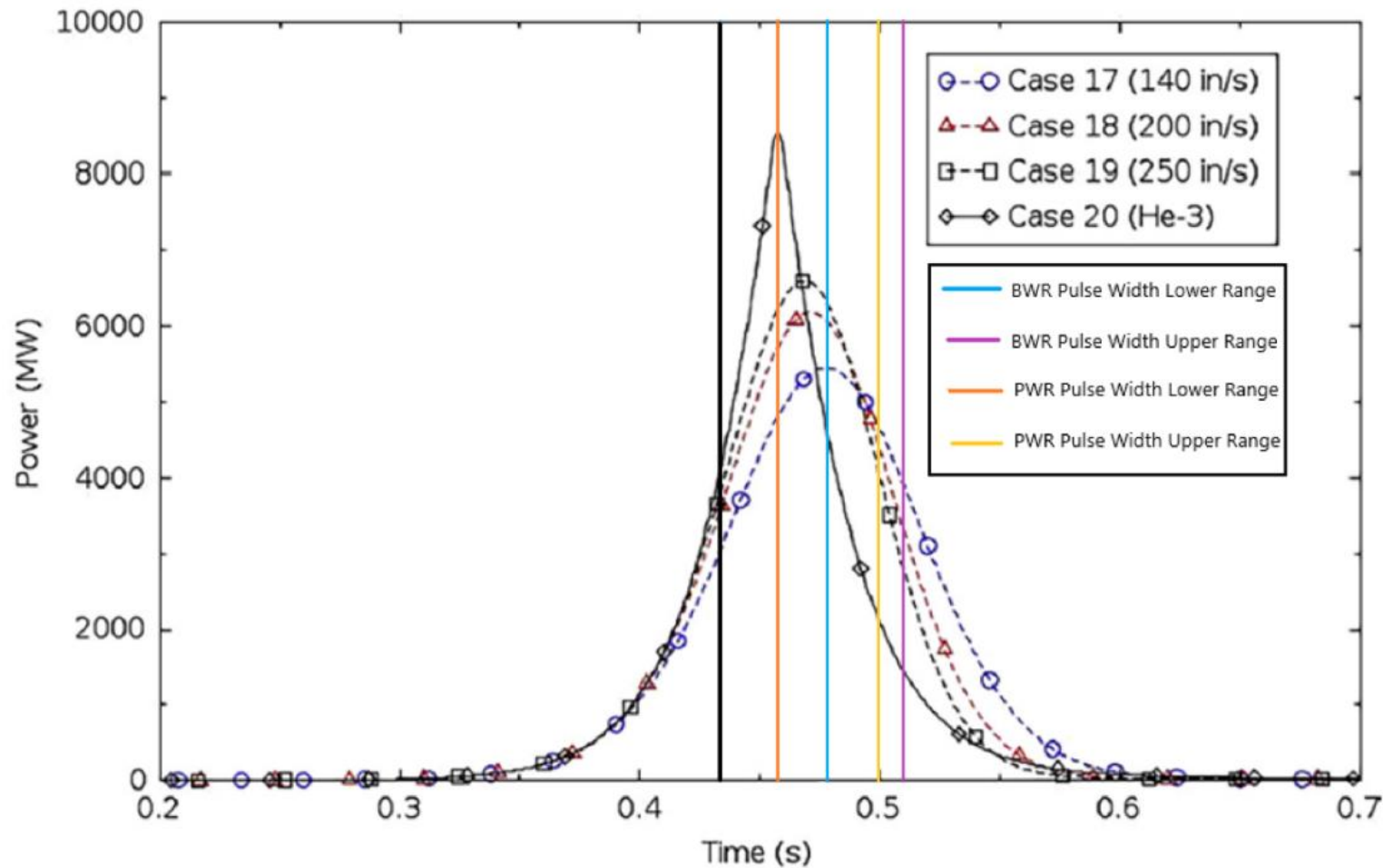
Reactivity Initiated Accidents (RIA)

- Reactivity events for Light Water Reactors (LWRs) are considered design basis accidents for the current nuclear fleet.
 - Loss of long-term cooling ability within the core
 - Damage to the pressure boundary or core of the reactor through the propagation of pressure waves.
- Fuel failure does not imply a loss of cool-ability or the creation of pressure waves, however, it is typically studied because it is a prerequisite which leads to such events.
- Desired fuel failure damage mechanisms are:
 - Cladding ballooning and burst
 - Embrittlement and failure by high temperature oxidation
 - Melting of fuel pellets and/or cladding



TREAT Current RIA Capabilities

- 3-dim lead to
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 - Fc
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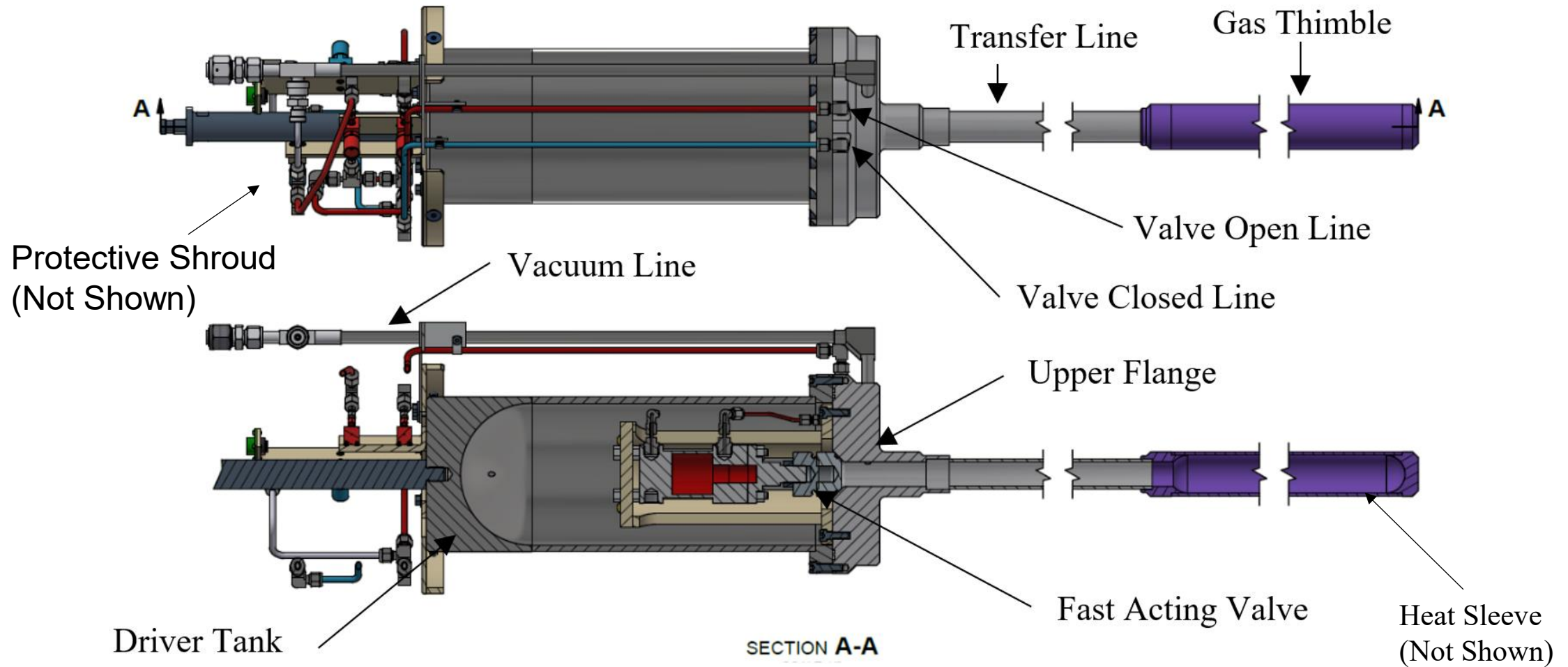
- Gaseous helium-3 – Winner, Winner!

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Helium-3 Negative Reactivity Insertion (HENRI) Needs

- Needs to add -5% $\Delta k/k$ reactivity
 - Max pulse is approximately 4.5% $\Delta k/k$
- Reactivity needed to be inserted in 5 ms or less
- Modular design
 - Add excess reactivity to the core by removing modules
- Symmetrical in the core
 - Maintain a symmetric flux

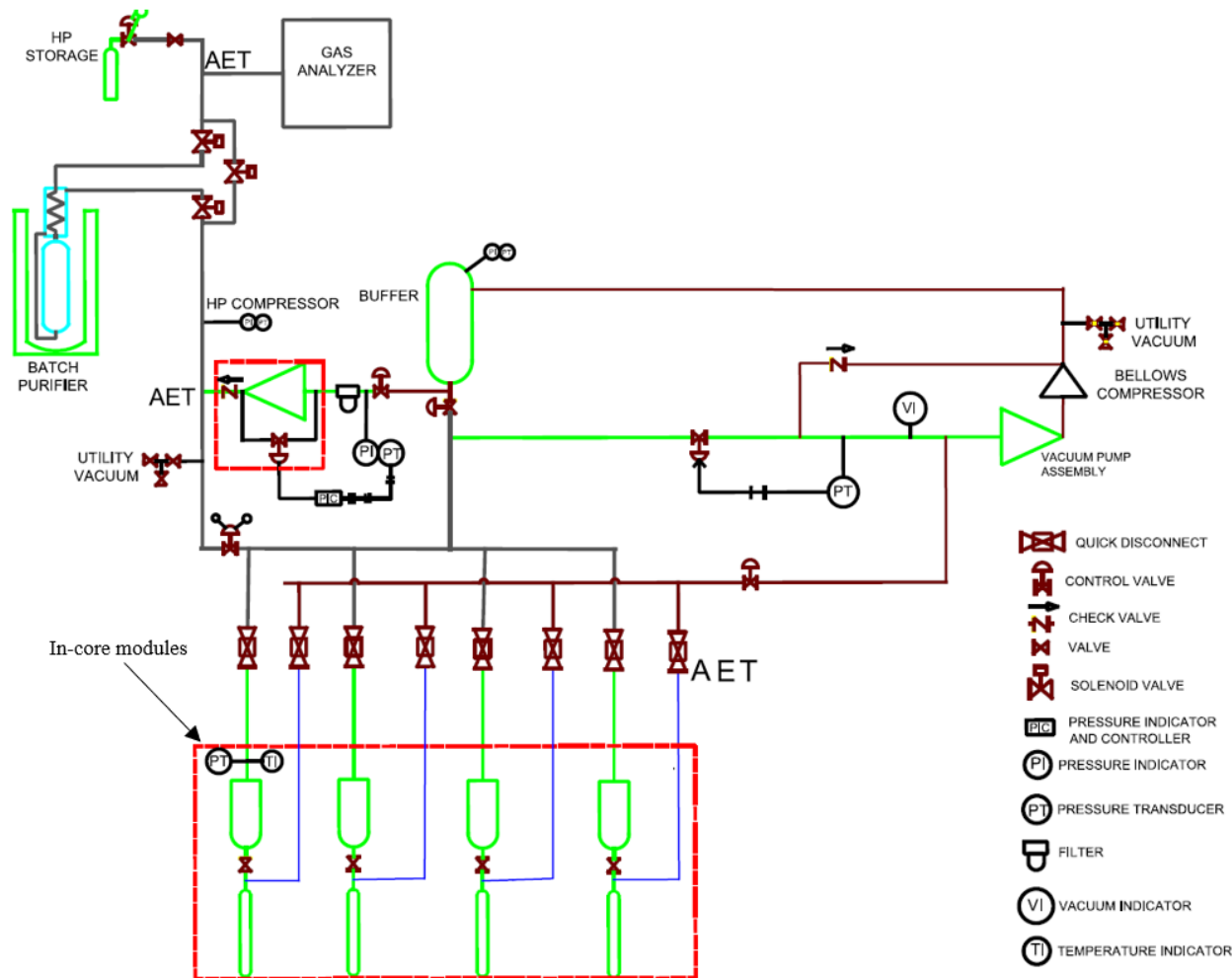
HENRI Module Design



HENRI Module Design

- Driver Tank – 6 liter storage of ~250 psig He-3 prior to transient.
- Transfer Line – Nominal 1” schd 40 line between active core region and Driver Tank. Also contains the interface flange for the Driver Tank.
- Gas Thimble – Nominal 1.5” schd 40 active region capsule.
- Valve Lines – Used for the opening and closing of the Fast Acting Valve.
- Fast Acting Valve – Triggered during transient to allow He-3 into the Gas Thimble through the Transfer Line.
- Heat Sleeve – Tight tolerance pipe to be put inside the Gas Thimble to absorb heat and reduce structural bending on the pressure boundary.
- Protective Shroud – Shroud to cover all solenoid valves at the top of the Driver Tank to reduce likelihood of damage during operations.

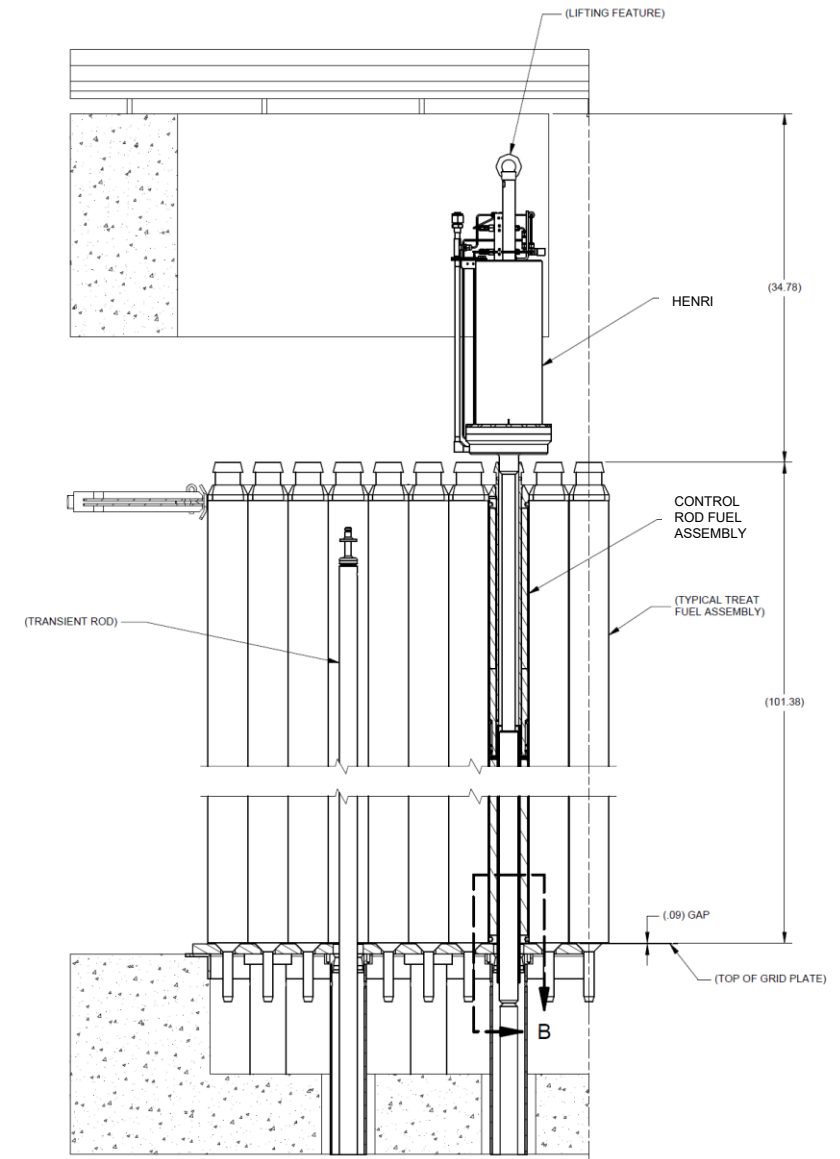
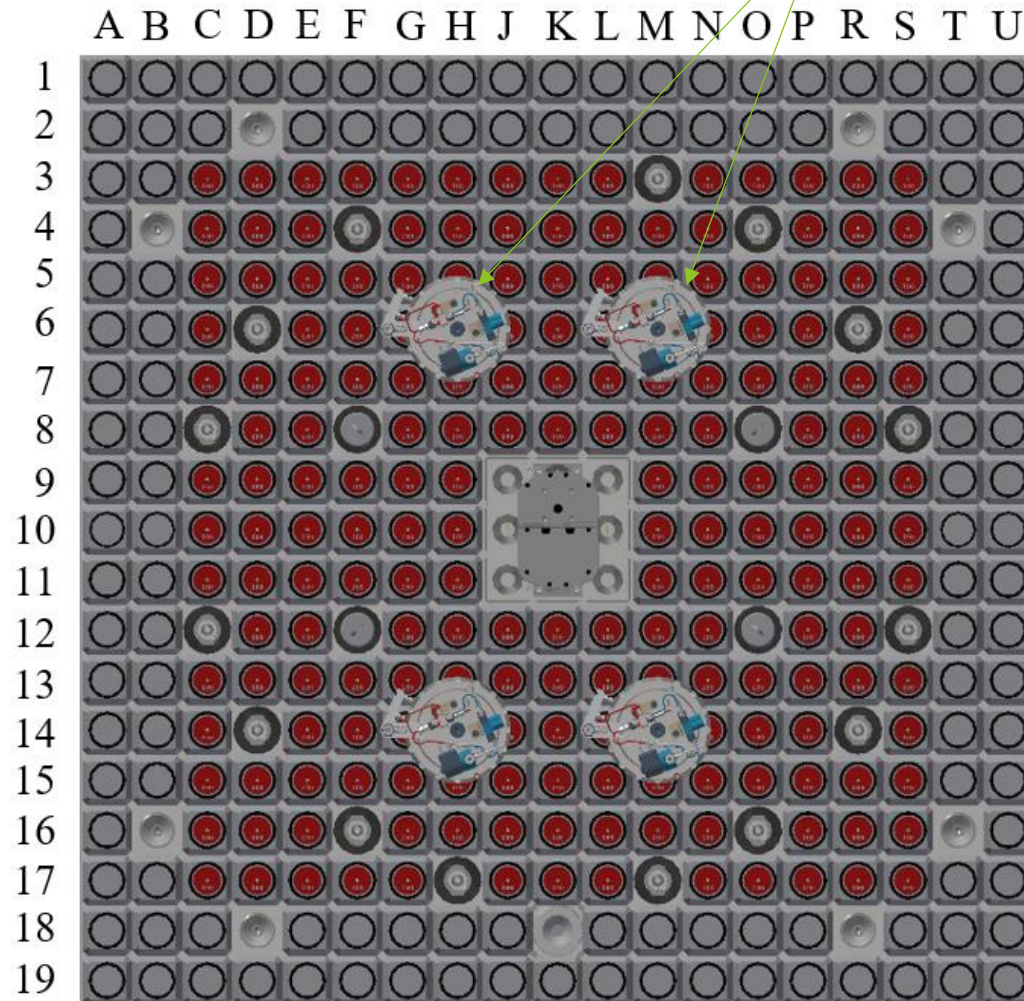
Recovery System



- Function:
 - Evacuate the Gas Thimbles pre- and post transient.
 - Provide low pressure storage when not in use, reduced leakage.
 - Ability to purify the He from potential contaminants.
 - Repressurize gas to high pressure as needed.

HENRI Configuration

HENRI Modules

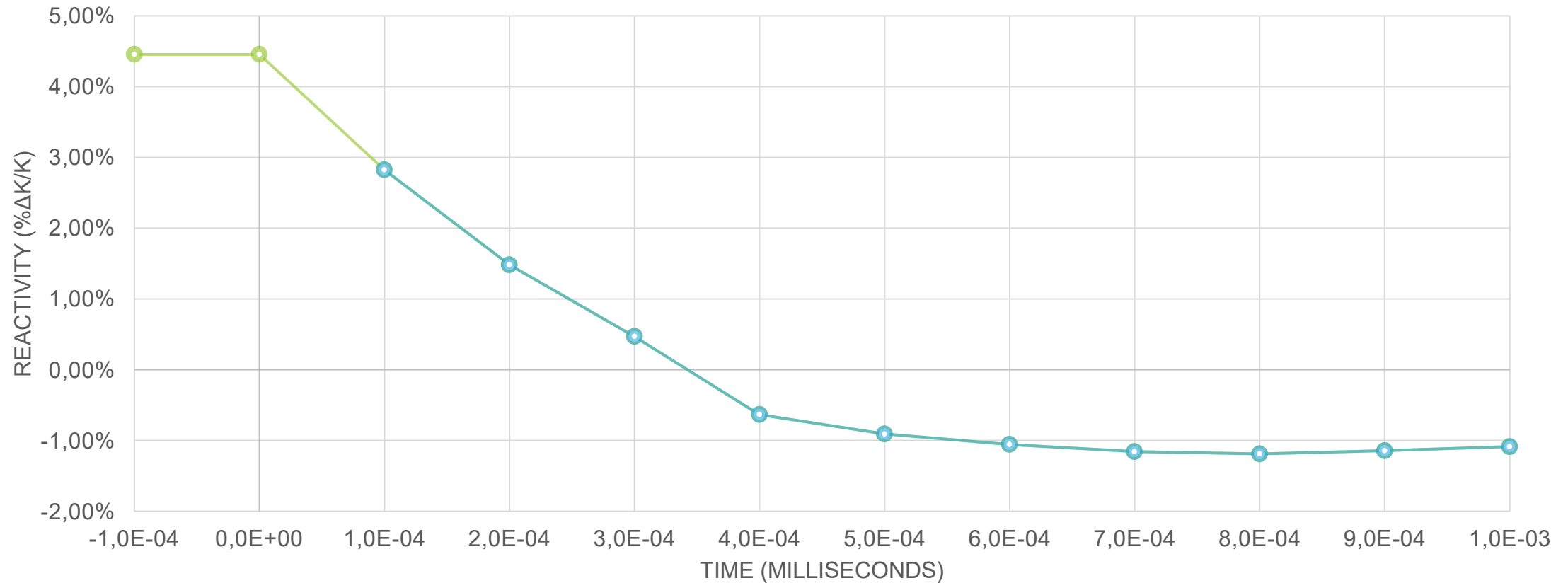


HENRI Operation

1. Pretransient
 - a. Pressurize gas to high pressure as needed (Recovery System)
 - b. Evacuate Gas Thimble (Recovery System)
 - c. Ensure Fast Acting Valve is closed (HENRI Module)
 - d. Fill Driver Tank to approximately 250 psig (Recovery System)
2. Transient
 - a. Open Fast Acting Valve (HENRI Module)
3. Post Transient
 - a. Remove gas from HENRI module (Recovery System)
 - b. Purify the helium gas (Recovery System)

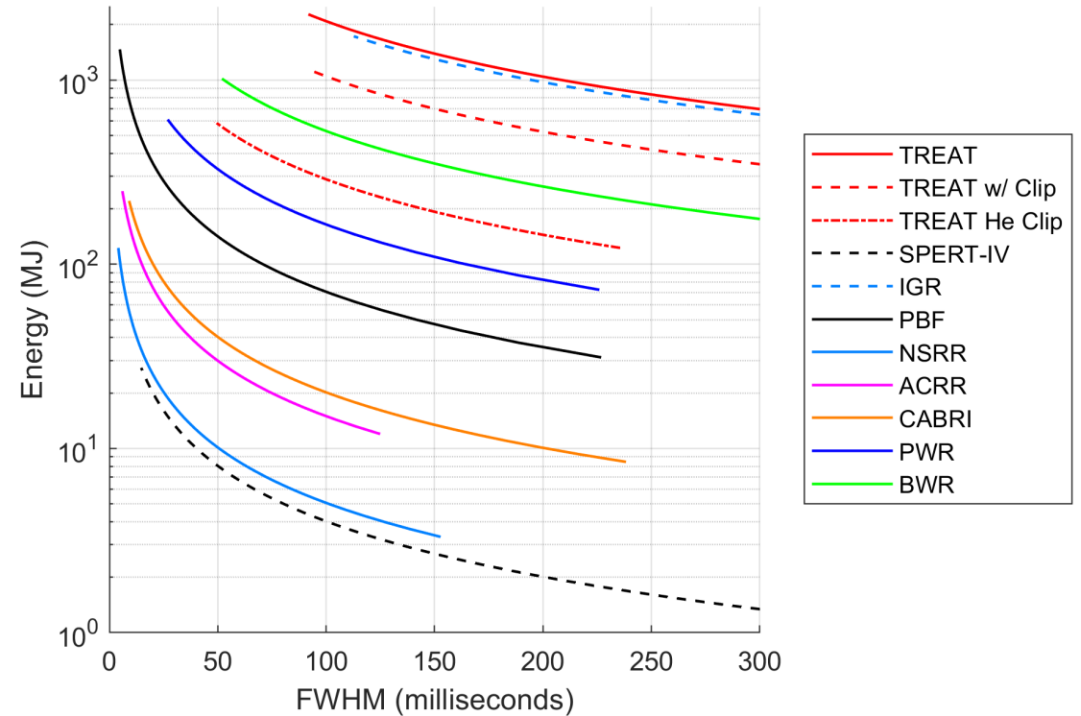
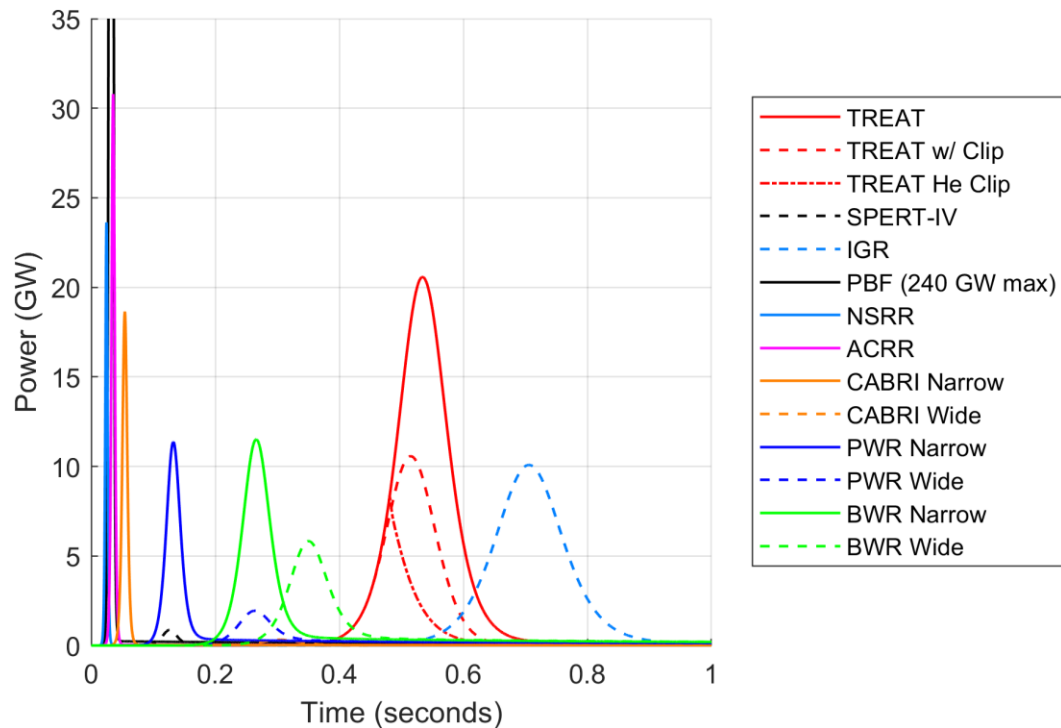
Analyzed Capability of HENRI

250 PSI Nominal



- @ 250 psig TREAT can achieve a clip in less than 4 ms from maximum pulse.

Analyzed Capability of HENRI



Comparison plots of TREAT with He-3 capabilities and LWR desired pulses along with other capabilities in the world.

References

- [1] C. Race, “Narrowing Pulse Widths Using Helium-3 at the Transient Reactor Test Facility (TREAT) – An Evaluation of the Helium-3 Negative Reactivity Injection (HENRI) System,” 2022
- [2] Argonne National Laboratory, "TREAT Baseline Description Document," 1992.
- [3] Idaho National Laboratory, "Transient Reactor Test (TREAT) Facility FSAR. SAR-420," 2022.
- [4] J. D. Bess, N. E. Woolstenhulme, C. B. Davis, L. M. Dusanter, C. D. Folsom, J. R. Parry, T. H. Shorthill and H. Zhao, "Narrowing transient testing pulse widths to enhance LWR RIA experiment design in the TREAT facility," *Annals of Nuclear Energy*, vol. 124, pp. 548-571, 2019.



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