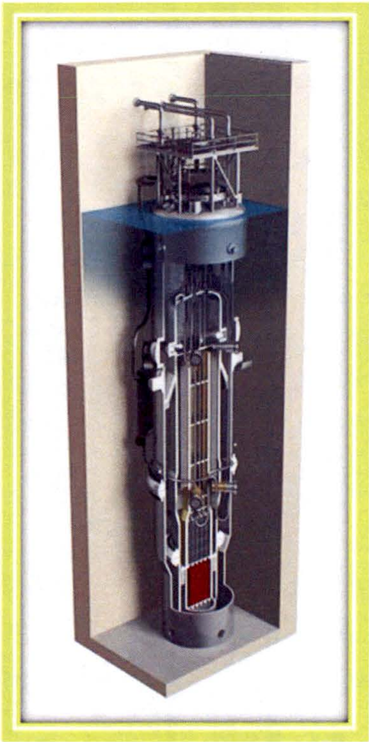
Shutdown Capability of the NuScale Power Module



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Acknowledgement & Disclaimer

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Outline

- GDC 27 Exemption
- NuScale Reactivity Control Systems
- Exemption Review Criteria
- Design Evaluation
- Summary

GDC 27 Exemption

- NuScale has identified the possibility of a return to power condition under very limited conditions and assumptions
  - Passive cooldown to low RCS temperatures is unique to NuScale design
- This condition was evaluated against the General Design Criterion
  - NuScale did not identify a need for an exemption and believes current design satisfies the GDC
    - Draft GDCs explicitly required systems to make core "subcritical"
    - Final GDCs revised by the Commission to address "controlling reactivity changes" to assure acceptable radiological consequences
    - NuScale design approach is consistent with literal language and intent of final GDCs
  - NuScale submitted a white paper on reactivity control (LO-1116-51829, Nov 2016) and addressed compliance with GDC 26 and 27 reactivity control functions
    - protection function: rapid power reduction to protect fuel, assuming WRSO, to protect fuel (AOOs under GDC 26) or to maintain core cooling capability to mitigate the consequences of accidents (DBAs under GDC 27)
    - shutdown function: capability to hold the core subcritical under cold conditions

GDC 27 Exemption

- NRC staff position (ML16116A083, Sep 2016) is that an exemption from GDC 27 is required
  - design departs from precedent (i.e., long-term shutdown with WRSO)
- NuScale complied with staff position and applied for exemption to GDC 27
  - whether or not an exemption is required, NuScale believes the design solution and safety demonstration are unchanged
- Exemption and FSAR establish PDC 27
  - Regulations require NuScale to define the PDCs for the design, and relation of the design bases to the PDCs
  - PDC 27 addresses precedent by explicitly defining requirement for long-term shutdown following postulated accident: NuScale design assures long-term shutdown with all rods in, but recriticality with WRSO would not exceed CHF:
    - *The reactivity control systems shall be designed to have a combined capability of reliably controlling reactivity changes to assure that under postulated accident conditions and with appropriate margin for stuck rods the capability to cool the core is maintained.*
    - *Following a postulated accident, the control rods shall be capable of holding the reactor core subcritical under cold conditions, without margin for stuck rods, provided the specified acceptable fuel design limits for critical heat flux would not be exceeded by the return to power.*

NuScale Reactivity Control Systems

- NuScale uses two primary reactivity control systems
  - safety-related control rods and nonsafety-related chemical volume and control system (CVCS)
- The selected reactivity control systems are consistent with NuScale design objectives for passive safety and simplicity
  - design does not use ECCS makeup with boron - typically the only safety-related boron injection for PWRs
  - Following transients, RCS passively cools down to low temperatures – not just to “hot shutdown”
  - Control rods alone maintain shutdown through entire RCS temperature range
- Assuming certain low probability conditions, there is a possibility of a return to power after a trip concurrent with a control rod malfunction (stuck rod)
  - late in core life (low boron concentration) and at low decay heat (core has cooled significantly), the small core with high control rod worth could experience a return to power if the highest worth rod is stuck out and AC power is not available to operate the active CVCS system
    - in all cases, reactor immediately shuts down after a trip using only control rods, even with WRSO
  - the reactor remains shut down under cold conditions with reliance only on control rods
    - indefinitely when all control rods are inserted, **or**
    - indefinitely with WRSO during first 70 percent of equilibrium fuel cycle, **or**
    - for 30 days (typical) assuming WRSO while decay heat remains above 100 kW* (negative reactivity feedback from voiding in the core limits return to power)

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Exemption Review Criteria

- NuScale believes maintaining core cooling is the design objective of reactivity control systems in GDC 27 (postulated accidents)
  - the "safety concern" for a return to power event is that it could challenge heat removal system capability such that the core is insufficiently cooled resulting in core damage
  - maintaining peak cladding temperature limits is considered sufficient to maintain core cooling
  - core cooling is conservatively demonstrated by maintaining CHF limits
- NRC's proposed criteria for an exemption to GDC 27 is conservative
  - maintain AOO acceptance criteria (CHF) and restrict frequency to less than that of an AOO (not expected in the life of a module)

Design Evaluation

	Deterministic Evaluation (Chapter 15)	Probabilistic Evaluation
Purpose	Evaluate safety	Evaluate shutdown reliability
Conservative assumptions	1. WRSO with limiting shutdown margin 2. MTC 3. Cooldown rate 4. Xenon and boron concentration 5. No credit for non-safety systems	1. CVCS failure on demand vs. less likely extended unavailability of CVCS and CFDS 2. Occurs throughout cycle vs. latter 30% of cycle 3. No decay heat after restart vs. more likely decay heat levels to prevent return to power
Probability	=1 under Ch 15 assumptions =0 that all assumptions will actually occur	<1E-6 per reactor module year
Event progression	1. Return to power at 2+ hrs with DHRS cooldown 2. ECCS actuates resulting in subcriticality - in less than 24 hours if AC and DC power is lost, or - after 24 hours with DC power available 3. Limiting condition for ECCS heat removal and CHF is subcriticality with maximum decay heat	1. Return to power during DHRS cooldown is prevented 2. Without AC power, ECCS actuates after 24 hours 3. Remains shut down until decay heat reduces to < 100 kW 4. Sufficient time to restore function to CVCS or CFDS to prevent a return to power
Criteria	CHF limit not exceeded	Not expected to occur during the life of a module

Design Evaluation

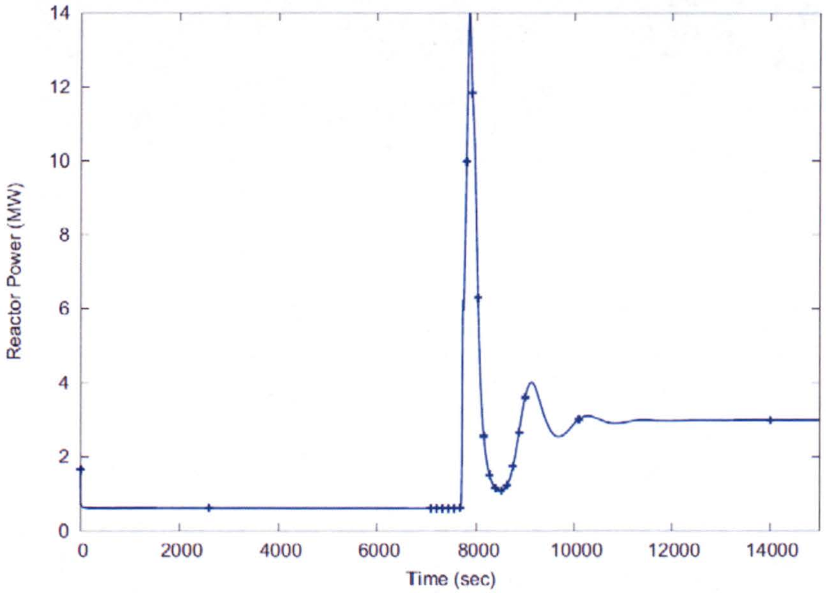
- The capacity of the NuScale passive heat removal systems (DHRS, ECCS) are sufficiently sized to ensure the core remains cooled, irrespective of control rod performance
  - core is protected after a return to power with a WRSO, or even after a failure to trip the reactor (ATWS)
- NuScale safely controls reactivity through natural, predictable, and reliable phenomena (negative void and reactivity feedback)
  - using additional systems to increase shutdown reliability will increase design complexity, reduce overall reliability and likely safety
    - licensed designs had to ensure subcriticality, using deterministic assumptions including a WRSO, to maintain core cooling (limit heat production within the capacity of decay heat removal systems).
  - DHRS heat removal characteristic in combination with negative moderator coefficient leads to self-limiting condition
    - higher power -> higher moderator temperature -> negative moderator feedback
  - ECCS heat removal characteristic in combination with moderator density decrease due to voiding leads to self-limiting condition
    - higher power -> lower moderator density due to voiding -> negative density feedback

Summary

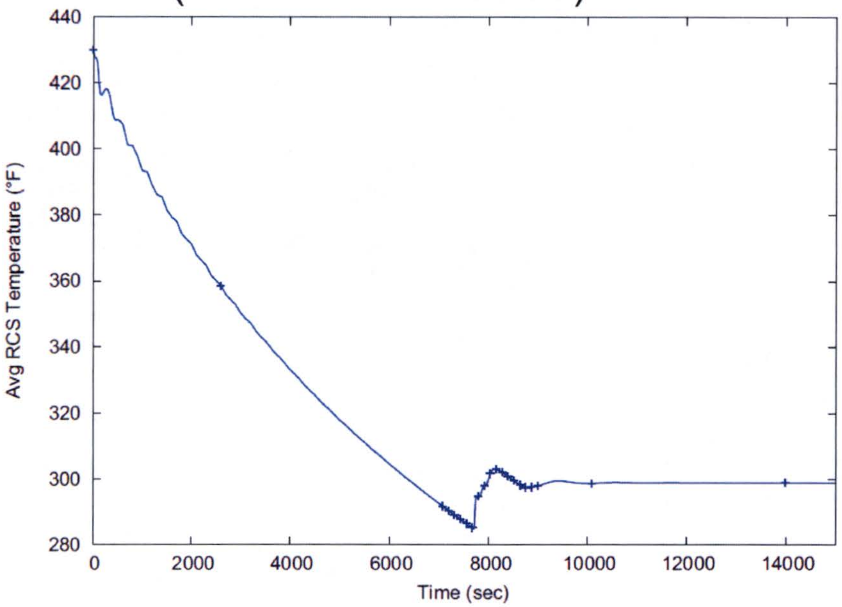
- NuScale is pursuing an exemption from GDC 27 consistent with NRC staff position
- Reactivity control systems are consistent with design objectives for simplicity and passive safety and provide
  - rapid shutdown to protect fuel
  - reliable capability to maintain subcriticality under cold conditions
  - passive heat removal that protects against control rod malfunctions
  - alignment with the NRC's advanced reactor policy statement (73 FR 26349; October 14, 2008) for an advanced reactor design
- A return to power with a WRSO is a benign low probability event with no radiological consequences

Backup Slides

Reactor Power (Peak Power Case, EDSS Available)

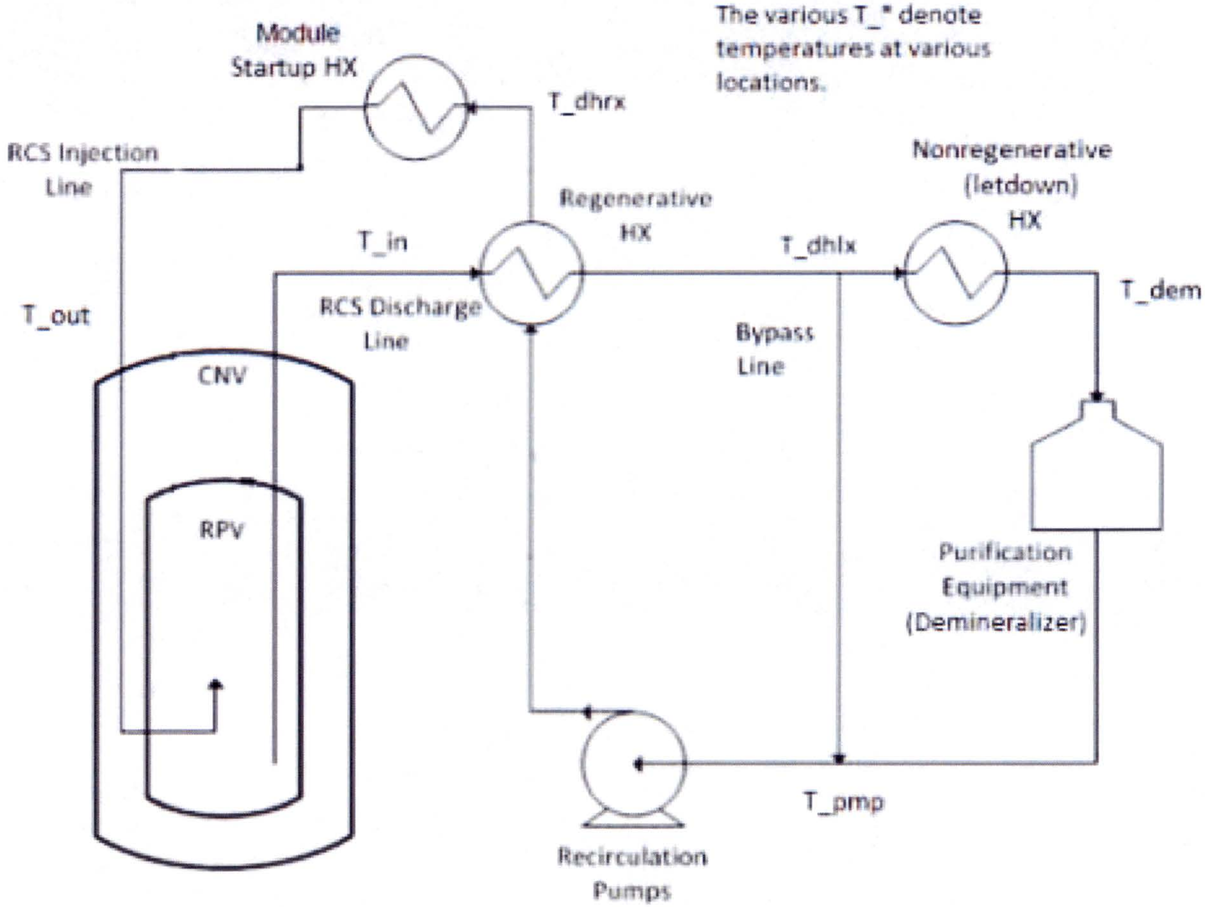


RCS Average Temperature (Peak Power Case)



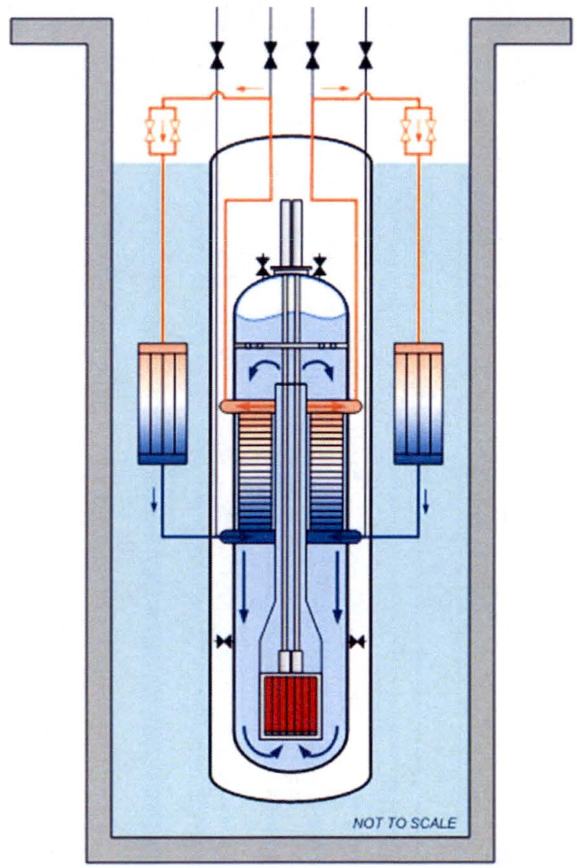
Backup Slides

Simplified CVCS Diagram



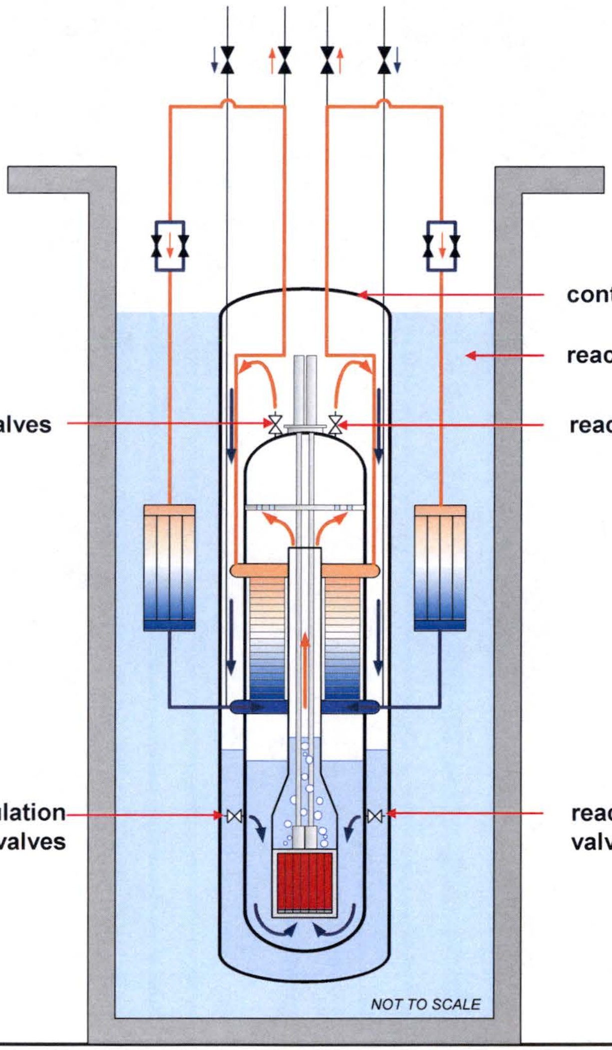
Design Overview: Passive Decay Heat Removal System

- Main steam and main feedwater isolated
- Decay heat removal (DHR) valves opened
- Decay heat passively removed via the steam generators and DHR heat condensers to the reactor pool
- DHR system is composed of two independent and redundant trains (1 of 2 trains needed)



Design Overview: ECCS and Containment Heat Removal

- Adequate core cooling is provided without the need for safety-related injection
- Reactor vent valves and reactor recirculation valves open on emergency core cooling system (ECCS) actuation signal
- Decay heat removed
  - condensing steam on inside surface of containment vessel
  - convection to the pool fluid on outside vessel wall



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