**Enclosure 1:**

"Reactivity Control, NuScale Design and Licensing," PM-0416-48568-NP, Revision 0, nonproprietary version

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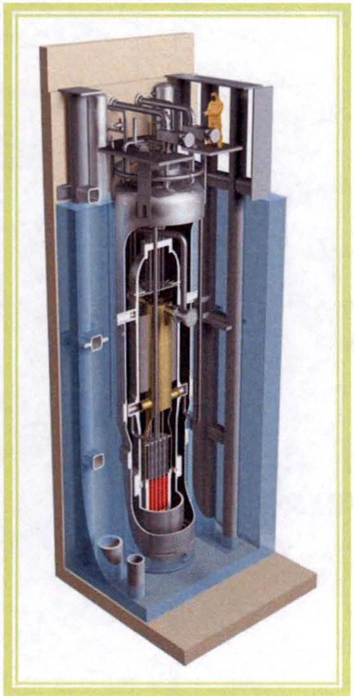
# Reactivity Control Design and Licensing Basis



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# Acknowledgement and Disclaimer

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# Abbreviations and Acronyms

| Term | Definition |
|---|---|
| AFW | auxiliary feedwater |
| AOO | anticipated operational occurrence |
| ATWS | anticipated transient without scram |
| BDBE | beyond design basis event |
| CVCS | chemical and volume control system |
| DBA | design basis accident |
| DBE | design basis event |
| DHRS | decay heat removal system |
| DSS | diverse scram system |
| ECCS | emergency core cooling system |
| EOC | end of cycle |
| FSAR | final safety analysis report |
| GDC | General Design Criterion |



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# Abbreviations and Acronyms

| Term | Definition |
|---|---|
| HPCI | high pressure coolant injection |
| LOCA | loss of coolant accident |
| MPS | module protection system |
| ORNL | Oak Ridge National Lab |
| RCIC | reactor core isolation system |
| RCPB | reactor coolant pressure boundary |
| RCS | reactor coolant system |
| RHR | residual heat removal |
| RSV | reactor safety valve |
| PCT | peak cladding temperature |
| SLCS | standby liquid control system |
| SSC | system, structure, and component |
| WRSO | worst rod stuck out |





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# Purpose

Establish that NuScale reactivity control systems

1. reliably shut down the reactor and maintain a shutdown condition (GDC 26),
2. support protection and safety system functions (GDC 26, GDC 27),
3. will be addressed in appropriate sections of the FSAR.

# Agenda

- Purpose
- Safety case
- Design description
- Secondary reactivity control system safety classification
- FSAR implementation – licensing basis
- Conclusion
- Additional material
  - Design comparison
  - Application of GDCs 26, 27, and 28 – design basis

# Safety Case

# Reliable Means for Shutdown

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}}2(a),(c)

# Core Heat Removal and Containment Integrity

- Heat removal capability is not challenged when reactivity control capability is not available (GDCs 26 and 27)

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}}2(a),(c)

  - CVCS soluble boron injection is not required to support core heat removal and containment integrity.

# Reliable Reactivity Control

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}}2(a),(c)

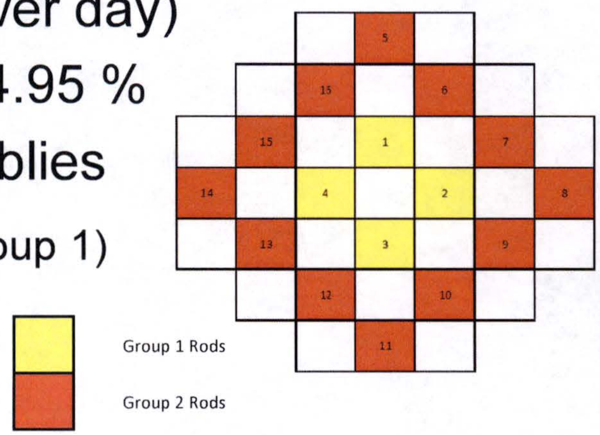
# Design Description

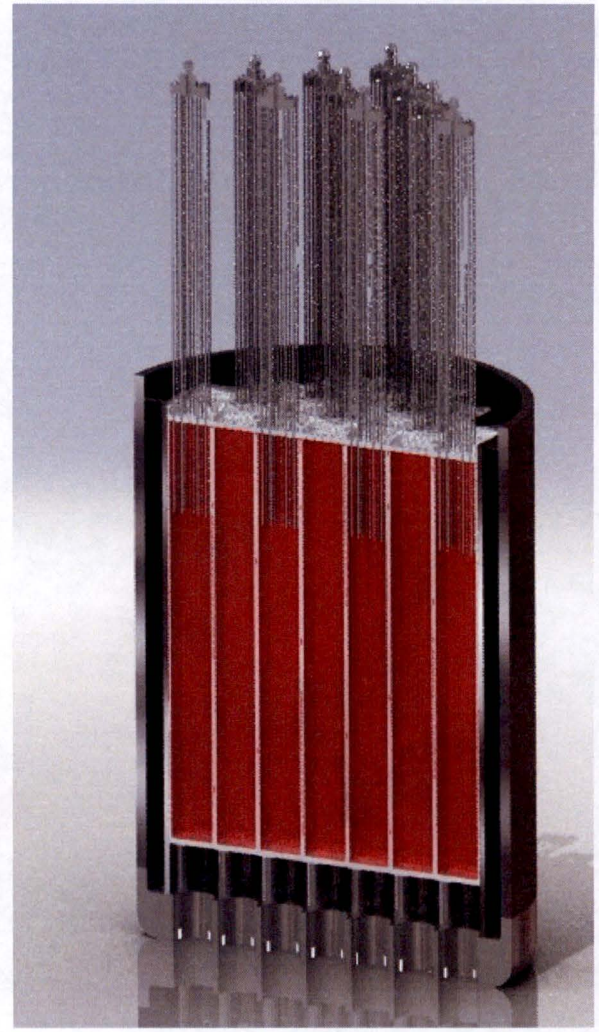
# Core Design: Basic Plant Parameters

| Reactor Core Description | |
|---|---|
| • Thermal power rating | 160 $MW_{TH}$ (gross) |
| • Nominal operating pressure | 12.7 MPa (1850 psia) |
| {{ | }}2(a),(c) ECI |
| • Number of assemblies | 37 |
| {{ | }}2(a),(c) ECI |
| • Refueling interval | 24 months |
| **Fuel Assembly Description** | |
| • Lattice geometry | 17x17 |
| • Enrichment | $UO_2$ (< 4.95% $U^{235}$ enrichment) |
| • Fuel Rods per Assembly | 264 |
| • Guide/Instr. Tubes per Assembly | 24/1 |
| {{ | }}2(a),(c) ECI |
| **Fuel Rod Description** | |
| • Active core height | 2.0 m |
| {{ | }}2(a),(c) ECI |
| • Clad material | M5® |
| • Fuel Pellet OD | 0.8115 cm |
| {{ | }}2(a),(c) ECI |
| {{ | }}2(a),(c) ECI |

# Reactor Core

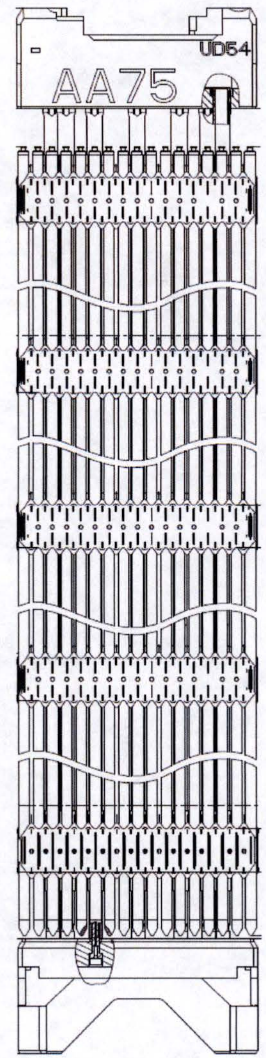
- 17x17 lattice
- Approximately half-height
- 37 fuel assemblies
- $UO_2$ fuel pellets
- Clad material – AREVA M5® advanced cladding
- Negative reactivity coefficients
- 24 month cycle length at 95% capacity factor (695 effective full power day)
- U-235 enrichment < 4.95 %
- 16 control rod assemblies
  - 4 in regulating bank (Group 1)
  - 12 in shutdown bank (Group 2)



# NuScale Fuel Assembly Design

- NuScale design based on AREVA's proven US 17x17 PWR technology
- NuScale design features
  - Zircaloy-4 HTP™ upper and intermediate spacer grids
  - Inconel 718 HMP™ lower spacer grid
  - coarse-mesh filter plate on bottom nozzle
  - Zircaloy-4 MONOBLOC™ guide tubes
  - quick-disconnect top nozzle
  - Alloy M5® fuel rod cladding




>> *Proven features with significant US operating experience*







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# NuScale Control Rod Assembly Design

- Control rod assembly design based on AREVA's proven US 17x17 PWR technology

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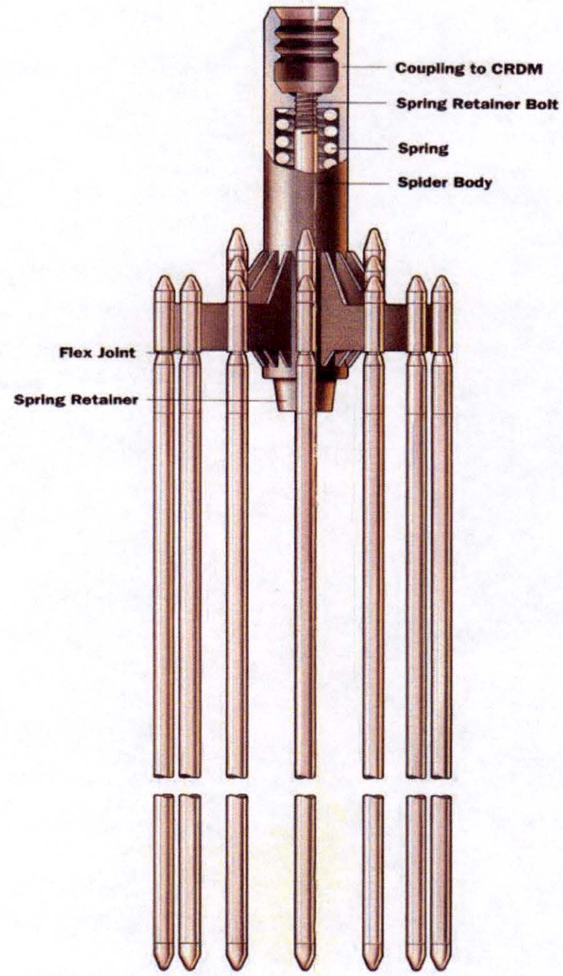
}}2(a),(c) ECI

  - 24 control rods with stainless steel cladding in each control rod assembly
  - one-piece cast stainless steel spider
  - flex joint formed by the combination of the pin, nut, upper end plug, and spider boss




>> *Proven features with significant US operating experience*



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# Control Rod Drive System Supports

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# ATWS Response

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}}2(a),(c)

# ATWS Chronology of Events

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}}2(a),(c)

# Energy Balance

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}}2(a),(c)

# Core Reactivity

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}}2(a),(c)

# Peak Cladding Temperature

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}}2(a),(c)

# RPV Pressure

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}}2(a),(c)





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# RCS Flow Rate

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}}2(a),(c)

# ATWS Scenario Summary

- ATWS is a benign event for the NuScale design
- Natural circulation of primary system is self-limiting on core reactivity

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}}2(a),(c)





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# Low Power Equilibrium Conditions for ATWS and Cooldown with WRSO

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}}2(a),(c)

# DHRS Heat Removal Without Reactor Trip (ATWS)

- Example: loss of feedwater results in pressure relief due to thermal expansion of RCS inventory

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}}2(a),(c)

# ECCS Heat Removal without Reactor Trip (ATWS)

- Example: inadvertent depressurization results in shutdown due to voiding, until voiding subsides

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}}2(a),(c)

# DHRS Heat Removal with WRSO

- Recriticality highly unlikely {{ }}$^{2(a),(c)}$
  - probability of a stuck control rod is low
  - after startup, higher concentration of soluble boron prevents recriticality prior to xenon buildup
  - recriticality occurs later than {{ }}$^{2(a),(c)}$ after shutdown when xenon decays (shortest time is at EOC)
  - can be delayed with manual or automatic ECCS actuation, or prevented with CVCS
- DHRS equilibrium condition of {{ }}$^{2(a),(c)}$ is well within system's capability to remove heat

# Reliability Assessment

- Bounding probability for reactivity control {{ }}2(a),(c) per year

{{

}}2(a),(c)

- Therefore, the reactivity control capability of the NuScale design is sufficient to reliably shut down the reactor and maintain a shutdown condition

# ECCS Heat Removal with WRSO

- Recriticality highly unlikely {{ }}2(a),(c)
  - precluded by voiding until decay heat reduces to less than {{ }}2(a),(c)
  - can be prevented by CVCS or containment flood and drain system
- ECCS equilibrium condition {{ }}2(a),(c) well within systems capability to remove heat
- Bounded by maximum decay heat of {{ }}2(a),(c) removed {{ }}2(a),(c) after shutdown

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}}2(a),(c)



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# Impact of Xenon and Time in Cycle

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}}2(a),(c)





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# Impact of Xenon

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}}2(a),(c)

# ECCS and DHRS Cooldown

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}}2(a),(c)

# Analysis with Chapter 15 Assumptions

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}}2(a),(c)

# Analysis with Chapter 15 Assumptions

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}}2(a),(c)

# Boron Precipitation

- Each NuScale module has a finite amount of boron in the RCS

{{ }}2(a),(c)

- There is no boron addition during a transient event
- The analytical model considers the transport of boron from all volumes of the RCS and containment into the core volume and the volume above the core
- Time-dependent thermal-hydraulic parameters are computed separately and are input into the model
- Preliminary results show that there is no boron solubility concern when the DHRS is actuated due to the temperature-dependent solubility limit of boron
- Preliminary results show that there is no boron solubility concern for ECCS actuation and long term core cooling in the reactor module

{{ }}2(a),(c)







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# Secondary Reactivity Control System Safety Classification



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# Reactivity Control Systems are Design Specific

| | NuScale | BWRs | Current PWRs |
|---|---|---|---|
| **Rapid shutdown** | Control rods (WRSO) | Control rods (WRSO) | Control rods (WRSO) |
| **Maintain shutdown conditions** | Control rods<br>(all rods inserted) | Control rods<br>(WRSO) | Control rods and soluble boron<br>(CVCS / ECCS) |
| **Backup to maintain shutdown conditions** | Soluble boron (CVCS)<br><br>If needed after an extended time in the unlikely event of a WRSO. Not needed to support protection or safety system functions. | Soluble boron (SLCS)<br><br>To protect containment function in case of failure to insert control rods. | N/A |







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# Design Differences with PWRs and BWRs

- Design difference for rapid shutdown
  - NuScale and PWRs: control rods drop in with gravity
  - BWRs: rods are inserted from below with hydraulic force
- Design differences in capability to maintain shutdown conditions
  - NuScale can maintain shutdown conditions with all control rods inserted
  - BWRs can maintain shutdown conditions with control rods inserted and a WRSO
  - PWRs requires control rods as well as soluble boron addition irrespective of a WRSO
- Design differences in safety classification of secondary reactivity control system
  - NuScale: CVCS classified as nonsafety related
  - BWRs: SLCS receives special treatment, classified as safety related in advanced designs
  - PWRs: CVCS receives special treatment, safety-related charging pumps for some designs

# Importance of NuScale Systems

- To identify protection and safety functions supported by NuScale reactivity control systems
  - considered a failure to scram
    - consequences of ATWS events do not challenge protection and safety system functions
  - considered a failure to remain shut down with an assumed WRSO
    - recriticality with an assumed WRSO does not challenge safety functions
- Compared protection and safety functions supported by NuScale with current generation BWRs and PWRs

# Importance of Capability to Maintain Shutdown Conditions

- NuScale relies on safety-related control rods, with all rods inserted, to maintain a shutdown condition
- Maintaining a shutdown condition is not needed to support safety system functions
  - power produced when not shut down with WRSO, or with all rods out (ATWS), does not result in a challenge to perform heat removal, inventory control or containment safety functions
  - CVCS not needed to support protection and safety system functions
  - reactivity control capability is sufficient to support protection and safety system functions, irrespective of CVCS reliability and availability

# Application of the WRSO Assumption

- For fuel protection, a WRSO is applied to provide *"margin for malfunctions such as stuck rods"* per GDC 26, irrespective of the likelihood of a stuck rod
  - for fuel protection, assuming a WRSO penalizes the rate at which negative reactivity is inserted when power needs to be rapidly reduced
  - applied to NuScale safety analysis consistent with precedent
- To maintain a coolable core geometry, PWRs assume a WRSO to provide margin when shutdown is relied on to support long term core cooling, i.e., to support the heat removal safety function
  - for the NuScale design, assuming a WRSO is not needed to provide margin to support the heat removal safety function. Maximum decay heat {{ }}2(a),(c) after shutdown {{ }}2(a),(c) is greater than the potential power produced when re-critical at EOC when relying on ECCS for heat removal {{ }}2(a),(c)




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# FSAR Implementation Licensing Basis

# FSAR Implementation

- Section 4.3
  - Description of reactivity control capability to meet GDC 26 and GDC 27
  - Shutdown margin
    - instantaneous shutdown margin address protection functions per GDCs 26 and 27
    - long-term shutdown margin address maintaining a shutdown condition per GDC 26
- Chapter 15
  - Evaluation of protection functions (fuel and RCPB)
- Chapter 19
  - Evaluation of shutdown capability
  - Low probability for recriticality

# Conclusion

# Conclusion

- NuScale reactivity control design meets underlying technical basis for all regulatory requirements
  - fuel and RCPB design limits are protected by rapid reactor shutdown using control rods (WRSO), similar to PWRs and BWRs
  - with all control rods inserted, a shutdown condition is maintained for all DBEs without the need for adding soluble boron
  - heat removal, inventory control, and containment safety functions are not challenged if shutdown cannot be maintained with WRSO, or for ATWS because of the passive heat removal capabilities of the ECCS and DHRS
  - probability of recriticality is less than {{ }}$^{2(a),(c)}$
  - bounding recriticality scenario does not require boron injection until {{ }}$^{2(a),(c)}$

# Advanced Reactor Policy Statement Alignment

- NuScale design aligns with the NRC's advanced reactor policy statement (73 FR 26349; October 14, 2008) for an advanced reactor design
  - "Highly reliable and less complex shutdown and decay heat removal systems. The use of inherent or passive means to accomplish this objective is encouraged (negative temperature coefficient, natural circulation, etc.)."
  - "Simplified safety systems that, where possible, reduce required operator actions, equipment subjected to severe environmental conditions, and components needed for maintaining safe shutdown conditions. Such simplified systems should facilitate operator comprehension, reliable system function, and more straightforward engineering analysis."
  - "Design features that can be proven by citation of existing technology, or that can be satisfactorily established by commitment to a suitable technology development program."

# Advanced Reactor Policy Statement Alignment

- Control rods provide sufficient protection and additional safety-related reactivity control capability is not needed in terms of overall safety
  - **Passive system reliability:** Low probability of a stuck rod {{ }}2(a),(c) compared to typical active ECCS unreliability {{ }}2(a),(c) After successful control rod insertion, no further operator actions are required for shutdown.
  - **Passive system simplicity:** Additional safety-related capability will increase design complexity, and introduces additional failure modes that could, for example, result in containment bypass.
- NuScale uses conventional external magnetic jack control rod drives because of extensive operating experience and well-documented reliability.

# Additional Material

## Design Comparison

# Importance to Safety Depends on Functions Supported

- Importance to safety of primary reactivity control system depends on support of protection and safety functions
- Importance to safety of secondary reactivity control system depends on support of safety functions
  - ORNL-NSIC-7, "Secondary Shutdown Systems of Nuclear Power Plants," Oak Ridge National Laboratory, Nuclear Safety Information Center, January, 1966.
  - Example from current generation PWRs: CVCS maintains shutdown conditions to support heat removal while cooling to cold conditions
    (RG 1.139 - Withdrawn)



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# LWR Rapid Shutdown Capability

- Reactivity control systems support protection system functions through rapid shutdown (short term)
  - make use of control rods (primary reactivity control system)
  - protect fuel integrity (GDCs 20, 26 for AOOs)
  - limit fuel damage (GDC 27, retain capability to cool the core for DBAs)
    - can use rods, or
    - soluble boron for overcooling and LOCA (not rapid shutdown)
  - protect reactor coolant pressure boundary (RCPB) integrity (GDC 15)
- Secondary reactivity control systems not relied on for rapid shutdown



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# LWR Capability to Maintain Shutdown Conditions

- Reactivity control systems support safety system functions through maintaining a shutdown condition (long term)
  - safety functions supported
    - reactor core heat removal
    - primary coolant system inventory control
    - containment integrity
  - make use of control rods, or soluble boron addition (secondary reactivity control system)

# Reactivity Control Capability for Different Plant Conditions

- Supporting functions of reactivity control systems are plant condition dependent
  - normal operation
  - DBEs
  - BDBEs, specifically ATWS
    - additional system capability or system reliability may be necessary to limit potential consequences
    - failure to rapidly shut down can result in fuel damage and RCPB overpressure (not mitigated by secondary systems)
    - failure to maintain shutdown condition can result in core damage or containment overpressure due to insufficient heat removal

# Importance of NuScale Systems

- To identify protection and safety functions supported by NuScale reactivity control systems
  - considered a failure to scram
    - consequences of ATWS events do not challenge protection and safety system functions
  - considered a failure to remain shut down with an assumed WRSO
    - recriticality with an assumed WRSO does not challenge safety functions
- Compared protection and safety functions supported by NuScale with current generation BWRs and PWRs

# NuScale Reactivity Control Capability

| Reactivity control capability | Plant condition | SSC | Protection and safety system functions |
|---|---|---|---|
| **Control reactivity changes during normal operation** | Normal power operation | CVCS and control rods | • Fuel integrity – sufficient negative reactivity is maintained to protect fuel through rapid shutdown with WRSO<br>• Fuel integrity – rod insertion limits are maintained to limit consequences of uncontrolled rod withdrawal and rod ejection<br>• Shutdown capability – sufficient negative reactivity is maintained to maintain in a shutdown condition with all rods inserted |
| **Rapid reactor shutdown (short-term response)** | DBEs and ATWS | Control rods (WRSO) | • Fuel integrity – prevent exceeding fuel design limits (CHF) |
| **Maintain shutdown condition (long-term response)** | DBEs and ATWS | Control rods (all rods inserted) | N/A |

# Design Description – BWRs

| Reactivity control capability | Plant condition | SSC | Protection and safety system functions |
|---|---|---|---|
| **Control reactivity changes during normal operation** | Normal plant operation | Control rods and burnable poison | • Fuel integrity – acceptable power distribution is maintained through manipulation of control rod patterns to protect fuel against overpower conditions<br>• Shutdown capability – sufficient negative reactivity is maintained to maintain a shutdown condition with rods inserted, except WRSO |
| **Rapid shutdown (short-term response)** | DBEs | Control rods (WRSO) | • Fuel integrity – prevent exceeding CHF or PCT |
| **Maintain shutdown condition (long-term response)** | DBEs | Control rods (WRSO) | • Containment integrity – prevents elevated containment temperatures and unstable condensation which cause excessive vibratory loads on containment structures |
| | ATWS | ARI or SLCS | |







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# Design Description – PWRs

| Reactivity control capability | Plant condition | SSC | Associated protection and safety system functions |
|---|---|---|---|
| **Control reactivity changes during normal operation** | Normal plant operation | Control rods, CVCS and burnable poison | • Fuel integrity – sufficient negative reactivity is maintained to protect fuel through rapid shutdown with WRSO.<br>• Fuel integrity – rod insertion limits are maintained to limit consequences of uncontrolled rod withdrawal and rod ejection. |
| **Rapid reactor shutdown (short-term response)** | DBEs | Control rods (WRSO) | • Fuel integrity – prevent exceeding CHF or PCT<br>• RCPB integrity – prevent RCPB overpressure |
| | Main steam line break | Control rods (DSS for B&W and CE) | |
| | Large break LOCAs | N/A | |
| | ATWS | Control rods (DSS for B&W and CE) | |
| **Maintain a shutdown condition (long-term response)** | DBEs that rely on auxiliary feedwater and RHR for orderly shutdown | Control rods and CVCS | • Core cooling – limits heat production when relying on heat removal systems sized to remove decay heat (AFW and RHR). Allows for orderly shutdown and cooldown to cold conditions using natural circulation.<br>• Inventory control – preventing sustained elevated RCS pressures which would result in an excessive loss of coolant through pressure relief valves. |
| | Main steam line break | Control rods (WRSO) and accumulators | |
| | ATWS | Control rods and ECCS or CVCS | |
| | AOOs and LOCAs that result in RCS depressurization | Control rods (WRSO) and ECCS | • Core cooling – limits heat production when relying on heat removal systems sized to remove decay heat (RHR).<br>• Containment integrity – prevents containment overpressure when relying on containment heat removal systems sized to remove decay heat (Containment spray and containment fan cooler system). |
| | Large break LOCAs | ECCS | |





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# Comparison of Importance of Rapid Shutdown Capability

- BWRs and PWRs rely on control rods (WRSO) to limit fuel damage (PCT)
- PWRs (B&W and CE) designs include a DSS which increases scram reliability to protect RCPB integrity
- NuScale relies on control rods (WRSO) to protect fuel design limits (CHF), similar to BWRs and PWRs
  - potential for ATWS reduced by incorporating diversity into MPS, equivalent to a diverse scram system (sufficient to reduce probability of ATWS consistent with SRP 15.8)
  - rapid shutdown not required to limit fuel damage (PCT) or protect RCPB integrity

# Comparison of Importance of Capability to Maintain Shutdown Conditions

- BWRs rely on control rods (WRSO) to support containment safety function
  - SLCS reliability and availability are considered important for ATWS mitigation. SLCS provides backup capability to support containment safety function in the unlikely event of a common cause mechanical failure, e.g. scram discharge volume, preventing control rod insertion.
- PWRs rely on control rods (WRSO) and CVCS to support heat removal safety functions for orderly shutdown
  - CVCS reliability and availability are considered important for orderly shutdown and cooldown to cold conditions. CVCS maintains shutdown conditions, which limits heat production when relying on heat removal systems sized to remove decay heat (AFW and RHR).

# Comparison of Importance of Capability to Maintain Shutdown Conditions

- NuScale relies on safety-related control rods, with all rods inserted, to maintain a shutdown condition
- Maintaining a shutdown condition is not needed to support safety system functions
  - power produced when not shut down with WRSO, or with all rods out (ATWS), does not result in a challenge to perform heat removal, inventory control or containment safety functions
  - CVCS not needed to support protection and safety system functions
  - Reactivity control capability is sufficient to support protection and safety system functions, irrespective of CVCS reliability and availability

# Additional Material

## Application of GDCs 26, 27, and 28 – Design Basis

# Interpretation of Intent of GDCs 26, 27 and 28

- Intent of GDCs interpreted from AEC's draft criteria (32 FR 10213; JULY 11, 1967), comments on draft criteria and precedent in applying GDC
- 21 organizations and individuals who commented are listed in Appendix B of SECY-R 143, "Amendment to 10 CFR 50 - General Design Criteria for Nuclear Power Plants," January 28, 1971
- Available comments from 21 organizations and individuals were reviewed

# GDC 26 "Reactivity control system redundancy and capability"

- Four draft criteria were combined to make up GDC 26
- Each sentence in GDC 26 deals with different aspects of reactivity control based on respective draft Criteria 27 through 30
- ORNL general comment: Group of criteria should distinguish between
  - function of dynamic reactivity control to protect fuel design limits
  - function for static hold down
- ORNL general comment: Reliability of each function depends on seriousness of consequences of a failure of that function
- GDC 26 was worded to distinguish between capability for controlling reactivity changes to protect fuel design limits, and capability to maintain a shutdown condition





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# GDC 26 – 1st Sentence

- GDC 26 "Two independent reactivity control systems of different design principles shall be provided."
  - based on draft criterion 27, which implied redundant capability
    - Comments were made on the "redundancy" of reactivity control as stated by Criteria 27 and as addressed by draft criterion 28 through 29. Specifically, comments to require redundant shutdown capability for designs where containment cannot be isolated without shutdown, and comments that PWR reactivity control systems are not redundant, but rather complementary.
    - Criteria was changed from requiring "at least" two systems based on comment from Westinghouse Electric Corporation: "Since these criteria are essentially minimum requirements, the phrase 'at least' is redundant."
    - Consistent with Appendix A, the "General Design Criteria establish minimum requirements for the principal design criteria for water-cooled nuclear power plants."
    - Thus, design capability may exceed the minimum capability required by the GDCs to address design specific safety considerations. For example, BWRs provide redundant means to maintain a shutdown condition that is more than the minimum capability required by GDC 26.

# GDC 26 – 1st Sentence

- GDC 26 "Two independent reactivity control systems of different design principles shall be provided."
  - NuScale design basis: design incorporates two independent reactivity systems, control rods, and the CVCS

# GDC 26 – 2nd Sentence

- GDC 26 "One of the systems shall use control rods, preferably including a positive means for inserting the rods, and shall be capable of reliably controlling reactivity changes to assure that under conditions of normal operation, including anticipated operational occurrences, and with appropriate margin for malfunctions such as stuck rods, specified acceptable fuel design limits are not exceeded."
  - Based on draft Criterion 29
    - function was changed from, "making the core subcritical sufficiently fast" to "controlling reactivity changes," which is more appropriate for preventing fuel damage, i.e., reactivity during operation should be controlled such that after a transient or AOO, negative reactivity available for insertion, with appropriate margin for stuck rods, is sufficient to ensure rapid power reduction to protect fuel design limits.
    - Address reactivity control to protect fuel design limits rather than shutdown
  - Design basis: during normal operation, sufficient negative reactivity is maintained (instantaneous shutdown margin) with control rods to ensure that the fuel design limits will be protected by rapid control rod insertion with an assumed WRSO.

# GDC 26 – 3rd Sentence

- GDC 26 "The second reactivity control system shall be capable of reliably controlling the rate of reactivity changes resulting from planned, normal power changes (including xenon burnout) to assure acceptable fuel design limits are not exceeded."
  - Based on draft Criterion 28
  - NuScale design basis: during normal operation, CVCS is used to adjust the target boron concentration during power changes to shutdown margin (instantaneous shutdown margin used in safety analysis) and rod insertion limits prior to an AOO to protect fuel design limits.



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# GDC 26 – 4th Sentence

- GDC 26 "One of the systems shall be capable of holding the reactor core subcritical under cold conditions."
  - Based on draft Criterion 30
    - Included the statement "with appropriate margins for contingencies" in contrast to draft Criterion 29, which required "Shutdown margins greater than the maximum worth of the most effective control rod when fully withdrawn shall be provided." For the function of rapid reactivity reduction to protect fuel design limits, GDC 26 requires "appropriate margin for malfunctions such as stuck rods." For the function of maintaining a shutdown condition, draft Criterion 30 and GDC 26 do not require margin for stuck rods.
    - Comments indicated that for some designs the function to maintain a shutdown condition was of lesser importance in terms of protecting public health and safety, and therefore margin for stuck rods was not required.

      "Further, the public health and safety will not be compromised by a return to low power."

      "We have inserted the words 'in a timely fashion' to clarify the criterion so that it does not arbitrarily rule out a short return to criticality during the shutdown transient."

# GDC 26 – 4th Sentence

- GDC 26 "One of the systems shall be capable of holding the reactor core subcritical under cold conditions."
  - Based on draft Criterion 30
    - Included the statement "under any conditions ". Several comments indicated the recommendation that this requirement applies to accident conditions. These comments were not implemented. Rather, GDC 26 specifies "holding the reactor core subcritical under cold conditions." Based on precedent, this requirement has been applied to AOOs.
  - NuScale design basis: Control rods, with all control rods inserted, can maintain the reactor shutdown under cold conditions (long term shutdown margin).





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# GDC 27 "Combined reactivity control systems capability"

- GDC 27 "The reactivity control systems shall be designed to have a combined capability, in conjunction with poison addition by the emergency core cooling system, 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."
  - not included in draft criteria
  - does not require achieving or maintaining a shutdown condition
  - "combined capability" refers to functions from second and third sentence of GDC 26, which addresses "reliably controlling reactivity changes"
  - reliance on "poison addition by the emergency core cooling system" is allowed for, but not required




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## GDC 27 “Combined reactivity control systems capability”

- GDC 27 “The reactivity control systems shall be designed to have a combined capability, in conjunction with poison addition by the emergency core cooling system, 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.”
  - NuScale design basis: control rods are relied on for reactivity control under accident conditions
    - provides for rapid shutdown with WRSO
  - heat produced after a highly unlikely recriticality event, when assuming a WRSO to address “appropriate margin for stuck rods”, would be substantially less than maximum decay heat levels removed with the ECCS



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# GDC 28 “Reactivity limits”

- GDC 28 “The reactivity control systems shall be designed with appropriate limits on the potential amount and rate of reactivity increase to assure that the effects of postulated reactivity accidents can neither (1) result in damage to the reactor coolant pressure boundary greater than limited local yielding nor (2) sufficiently disturb the core, its support structures or other reactor pressure vessel internals to impair significantly the capability to cool the core. These postulated reactivity accidents shall include consideration of rod ejection (unless prevented by positive means), rod dropout, steam line rupture, changes in reactor coolant temperature and pressure, and cold water addition.”
  - based on draft Criterion 32
  - does not require margin for WRSO, although applied based on precedent
  - does not require achieving or maintaining shutdown condition
  - NuScale design basis:
    - as part of core design, limit potential reactivity insertion rate from reactivity accidents to limit event consequences, i.e., fuel damage and RCPB overpressure
    - during normal operation, maintain rod insertion limits to limit event consequences





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