Chapter 8 – Electric Power

Ted Hough
Supervisor, Electrical Systems

Matt Featherston
Nuclear Licensing Engineer

March 18, 2014

Nonproprietary

NUSCALE POWER™

Agenda

- Purpose
- Plant overview
- Background
- Electrical system design information
  - features/capabilities warranting unique electrical system design basis
  - electrical system design description
  - compliance with relevant GDCs and 10 CFR 50.63
- Information for NRC to develop NuScale, LLC (NuScale) Design-Specific Review Standard (DSRS) Chapter 8
- Results achieved and next steps

NuScale Power

Purpose

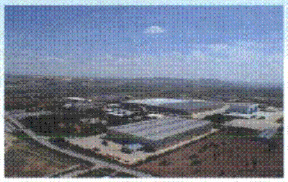
- Provide sufficient information for development of NuScale DSRS Chapter 8
  - design information
  - standard review plan (SRP)/DSRS information
- Describe compliance with GDCs and 10 CFR 50.63 (station blackout [SBO] rule)
- Identify need for future DSRS Chapter 8 engagements

NuScale Power™

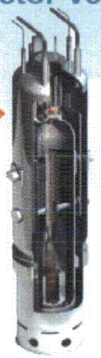
Plant Overview

Plant Design Overview

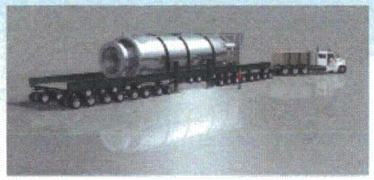
Factory Manufacturing



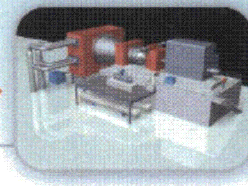
Module includes Containment and Reactor Vessel



Shipped by Truck, Rail, or Barge

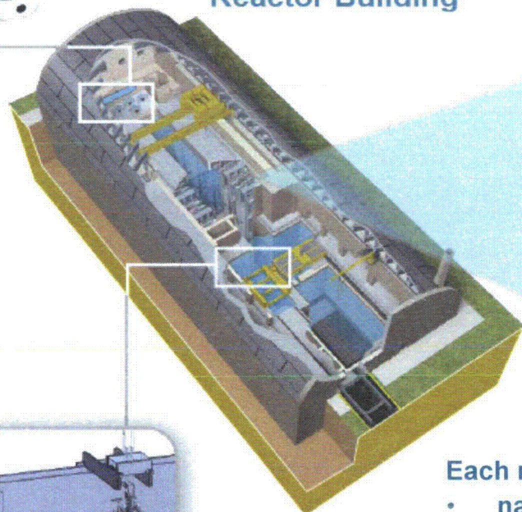


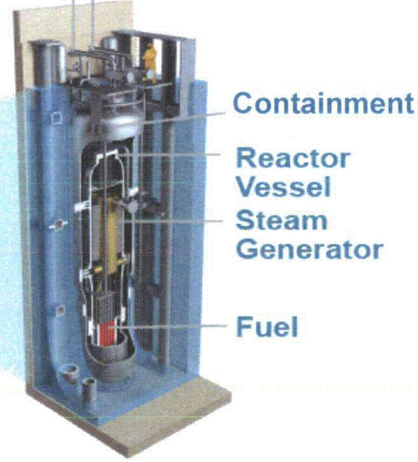
Skid-Mounted Steam Turbine/Generator



Below-Ground Control Room provides enhanced security and state-of-the-art controls

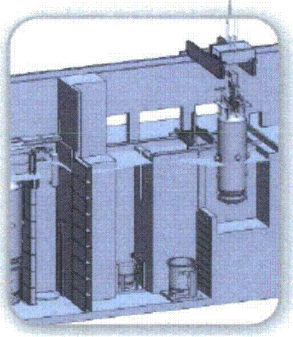
12 Module Reactor Building





Each Module is refueled underwater while the remainder of the plant produces power

- Refueled once every 24 months
- 10 Day Refueling Target

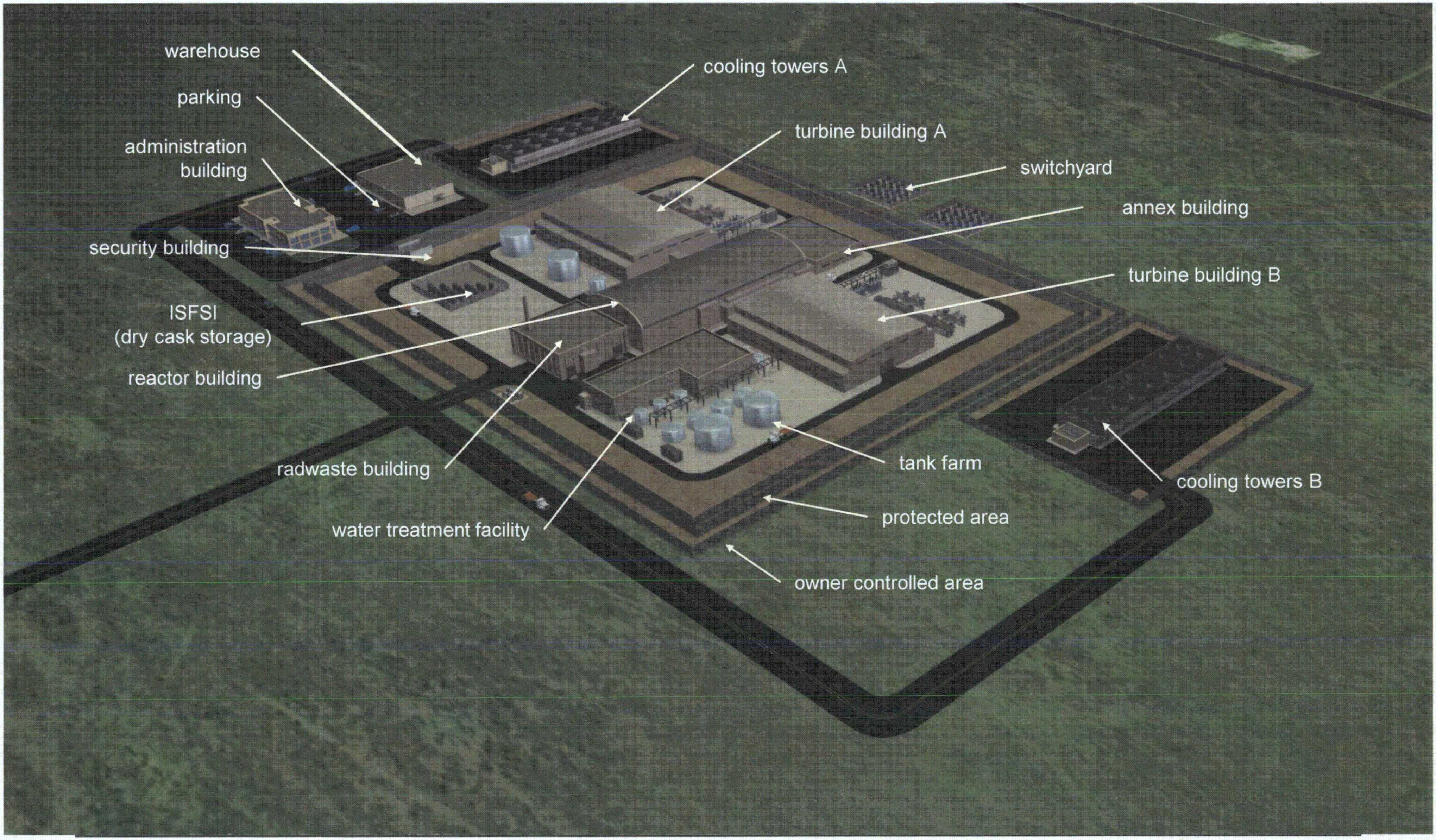


Each module installed in its own isolated bay

- **natural circulation (no reactor coolant pumps)**
- **37 standard 17x17 PWR fuel (half-height) fuel assemblies**
- **standard magnetic jack control rod drives**
- **internal helical coil steam generators and pressurizer**
- **45 MWe net power**

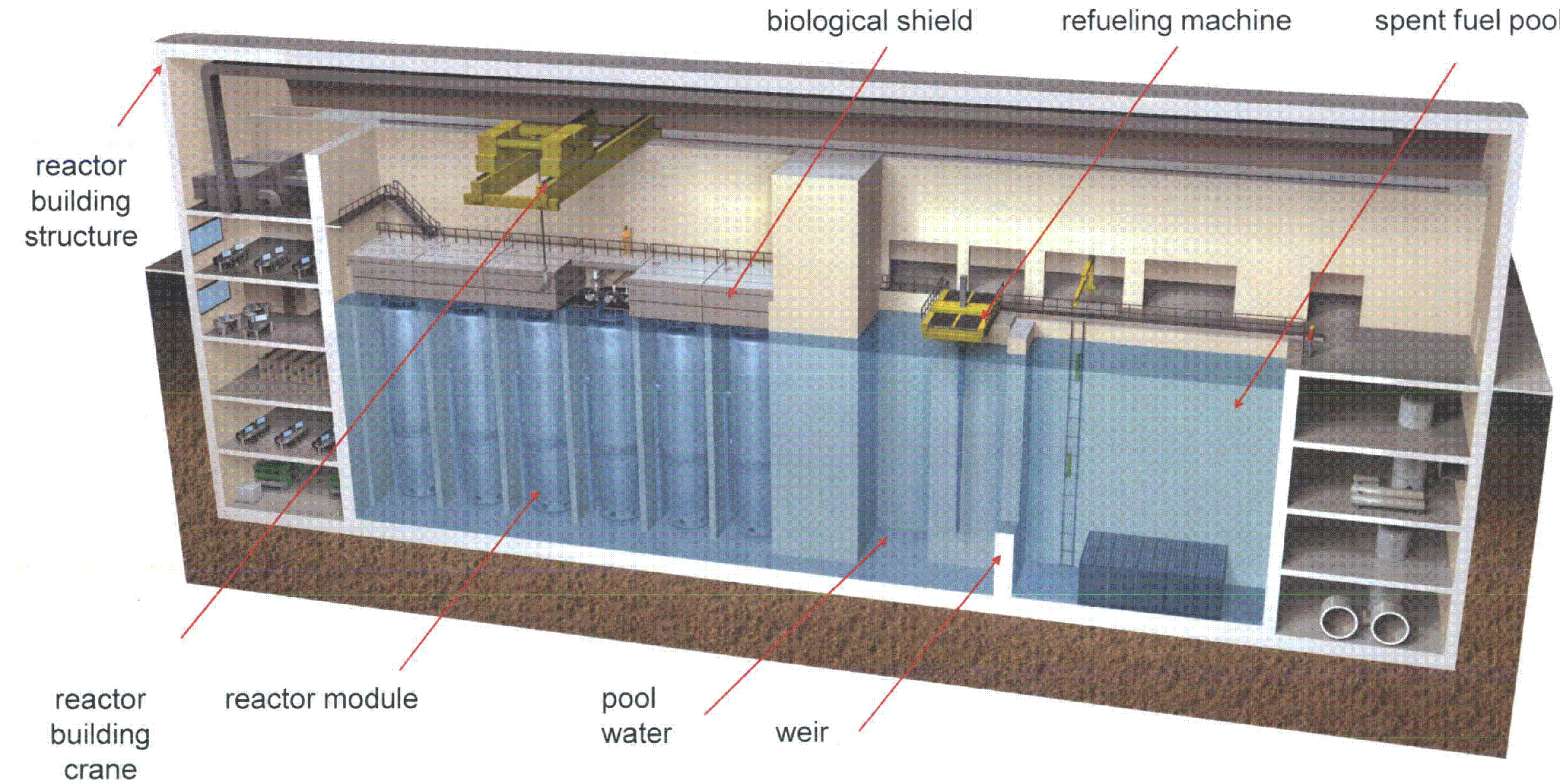
NuScale Power™

Site Aerial View



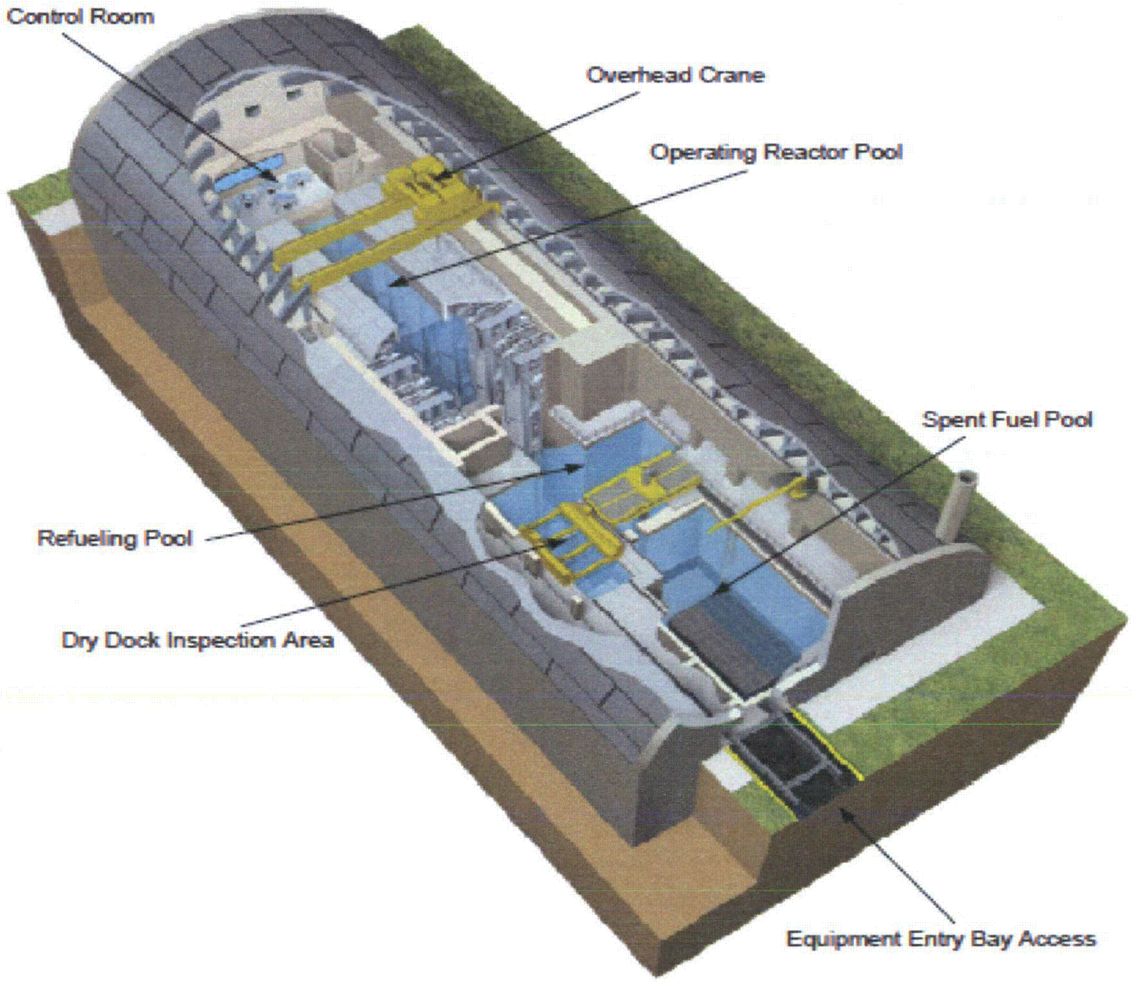
Reactor Building Cross-Section

Reactor building houses reactor modules, spent fuel pool, and reactor pool



NuScale Power™

Reactor Building Overhead View



Basic Plant Parameters

Overall Plant	
• Net electrical output	Up to 540 MW(e)
• Plant thermal efficiency	> 30%
• Number of power generation units	Up to 12
• Nominal plant capacity factor	> 95%
• Total plant area	~44 acres
Power Generation Unit	
• Number of reactors	One
• Net electrical output	45 MWe
• Steam generator number	Two independent tube bundles (50% capacity each)
• Steam generator type	Vertical helical coil tube (secondary coolant boils inside tube)
• Steam cycle	Superheated
• Turbine throttle conditions	3.3 MPa (475 psia)
• Steam flow	67.5 kg/s (536,200 lb/hr)
• Feedwater temperature	149° C (300 °F)
Reactor Core	
• Thermal power rating	160 MWt
• Operating pressure	12.7 MPa (1850 psia)
• Fuel design	UO_2 (< 4.95% U^{235} enrichment); 37 half height 17x17 geometry lattice fuel assemblies; Zircaloy-4 or advanced cladding material; negative reactivity coefficients
• Refueling interval	24 months

NuScale Power™

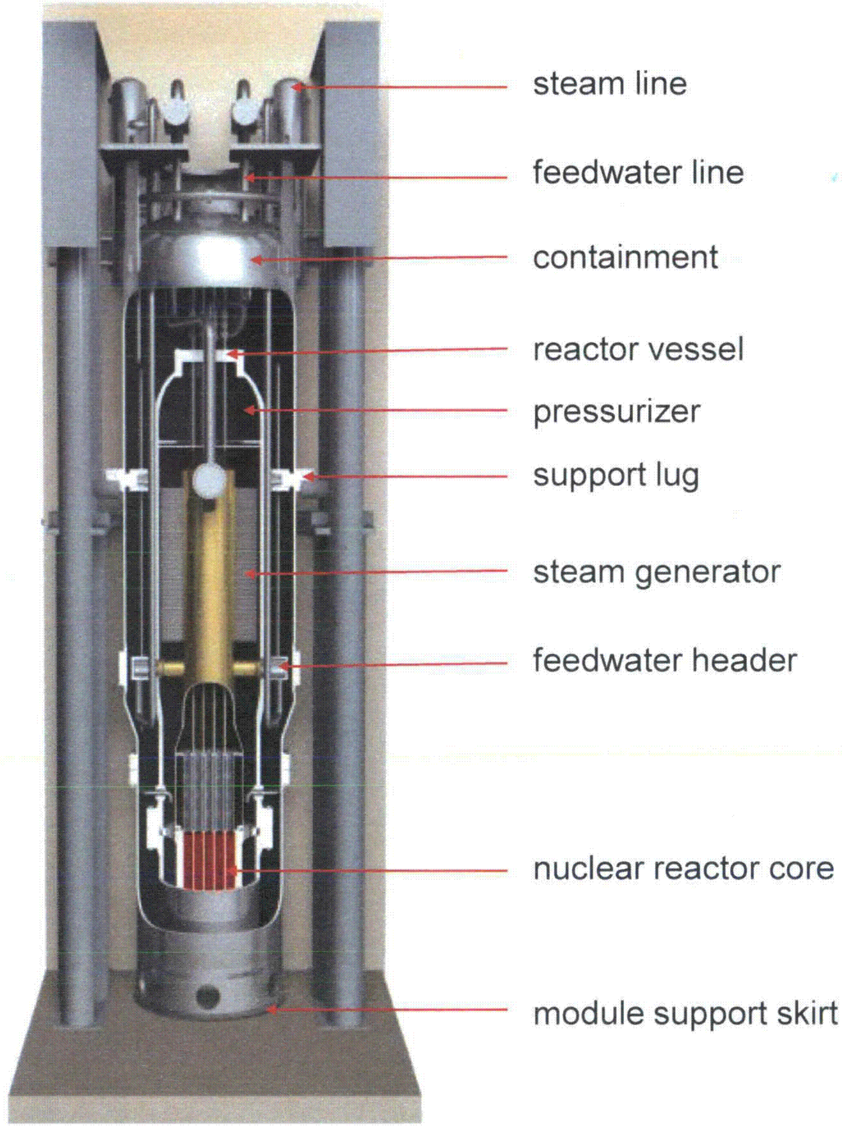
Reactor Module Overview

Natural convection for cooling

- passively safe, driven by gravity, natural circulation of water over the fuel
- no pumps, no need for emergency generators

Simple and small

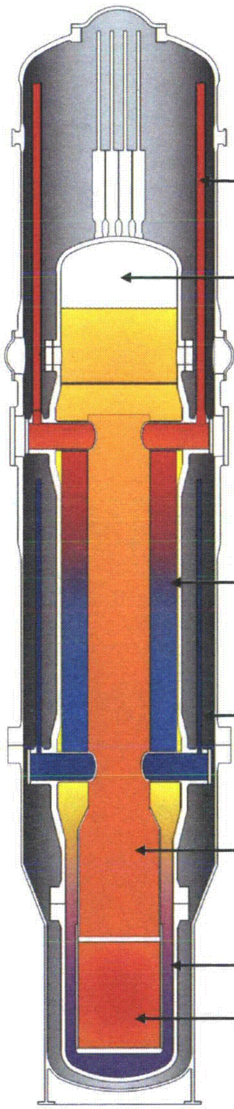
- reactor is 1/20th the size of large reactors
- integrated reactor design, no large-break loss-of-coolant accidents

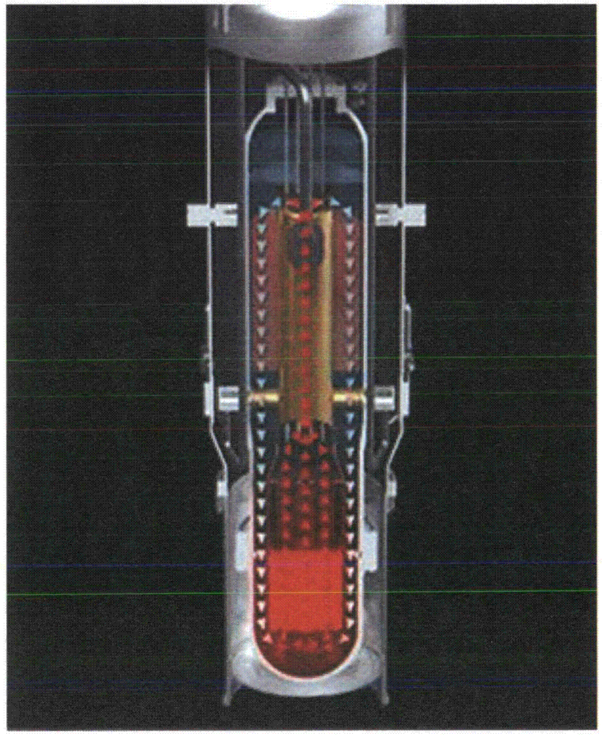


NuScale Power™

Module Normal Operation

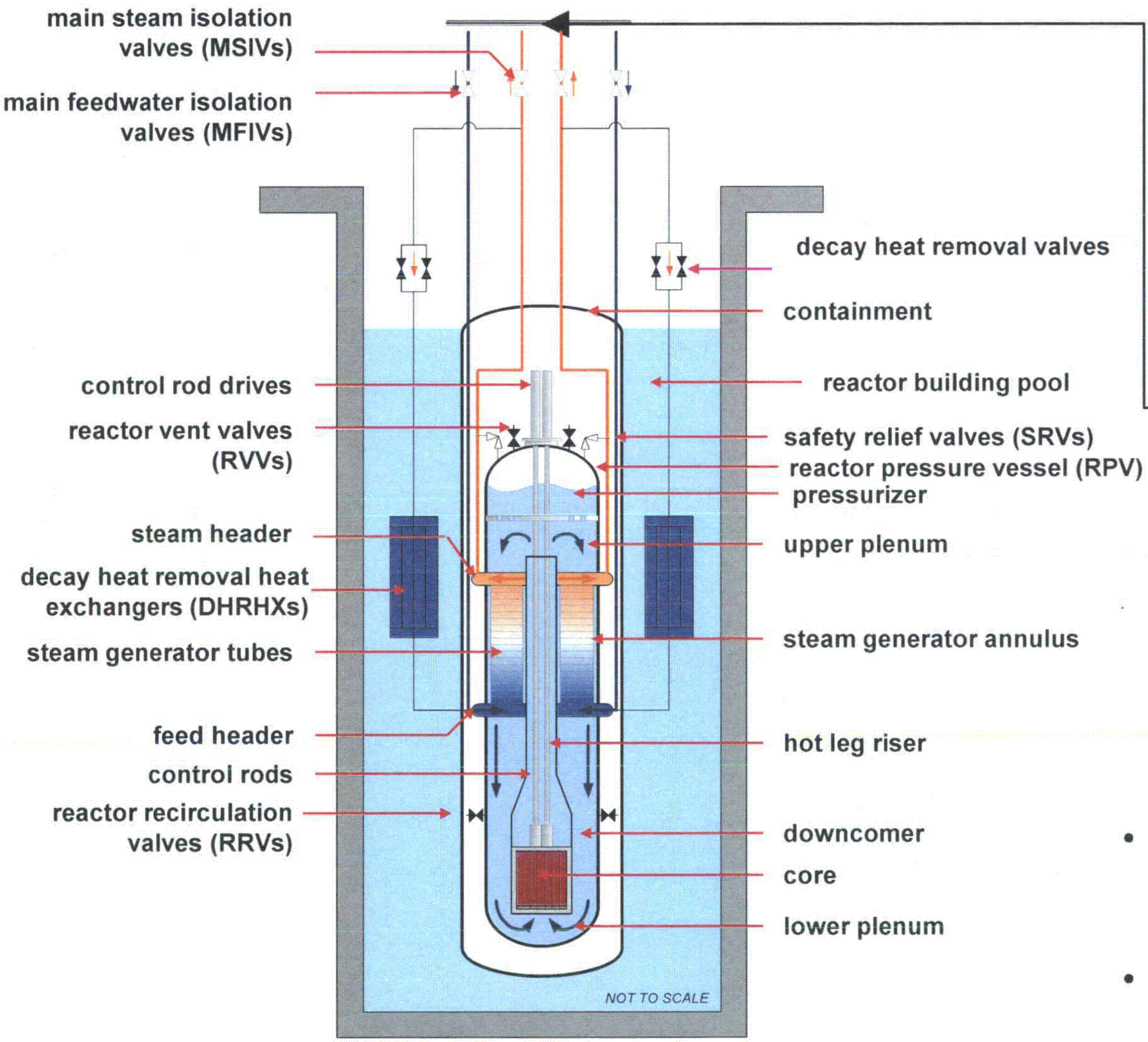
- Primary side
  - natural circulation
  - integral pressurizer
- Secondary side
  - feedwater plenums
  - two helical steam generators
  - steam plenums

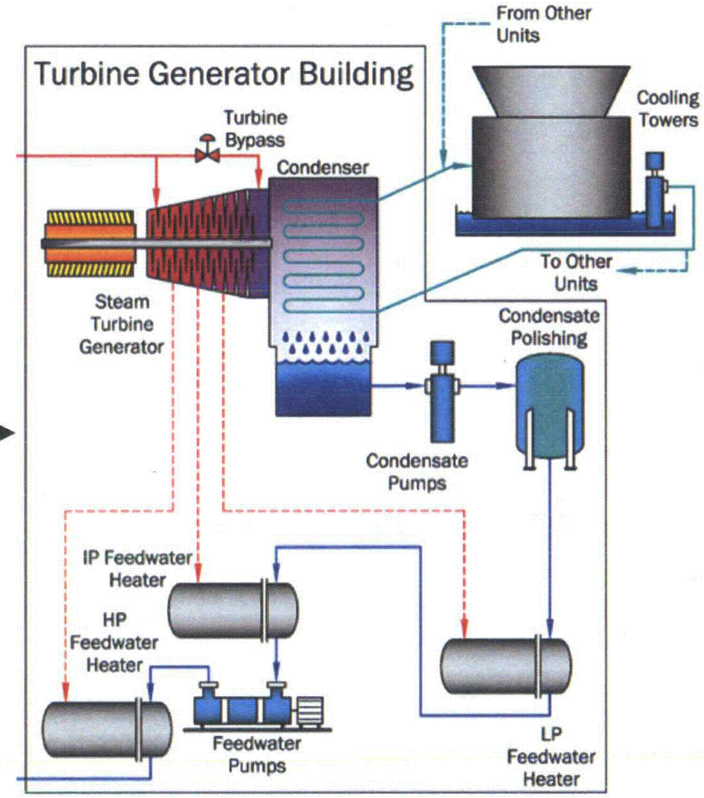




primary coolant flow path

NuScale Power Train





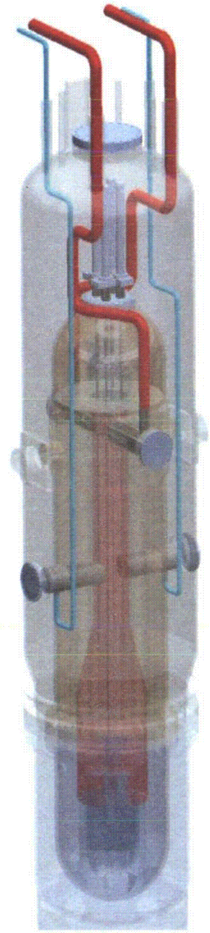
- Each reactor module feeds one T-G train eliminating single-shaft risk
- Small, simple components support short simple refueling outages

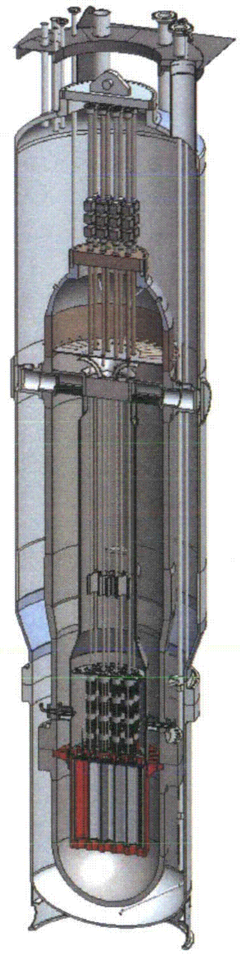
NUSCALE POWER™

Containment Design

High Pressure Containment – Enhanced Safety

- Containment volume sized so that core does not uncover following a loss-of-coolant accident (LOCA) (prevents fuel heat-up)
- Large water pool keeps containment shell cool and promotes efficient post-LOCA steam condensation
- Insulating vacuum
  - significantly reduces conduction and convection heat transfer during normal operation
  - requires no insulation on reactor vessel. Eliminates sump screen blockage issue (GSI-191)
  - improves LOCA steam condensation rates by eliminating air
  - prevents combustible hydrogen mixture in the unlikely event of a severe accident (i.e., little or no oxygen)
  - reduces corrosion and humidity problems inside containment

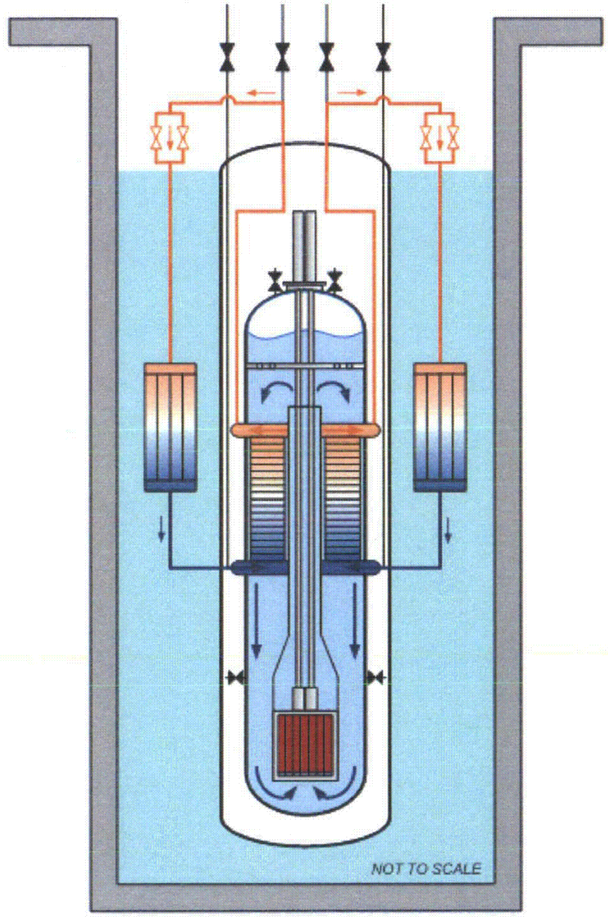




NuScale Power™

Passive Decay Heat Removal System

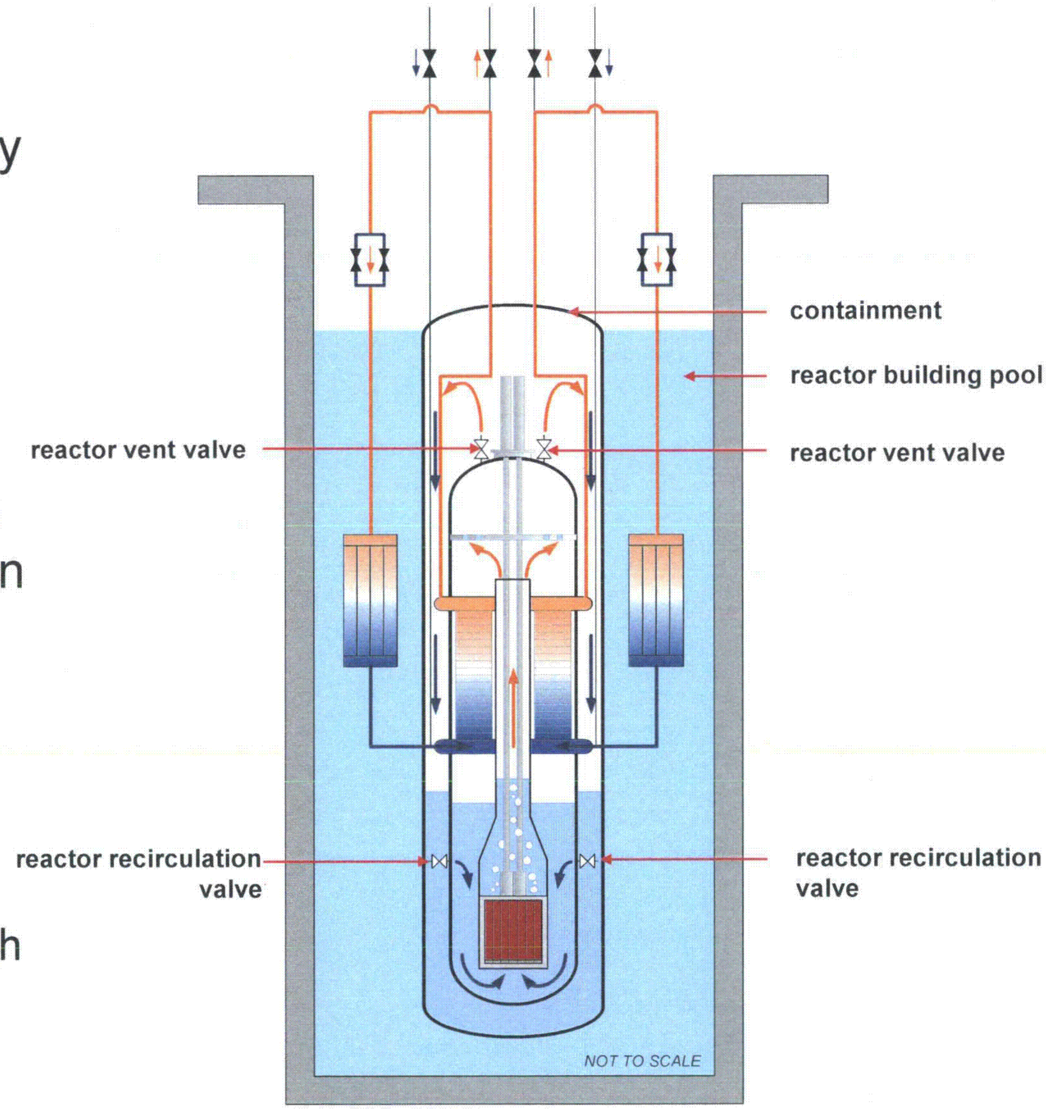
- Main steam and main feedwater isolated
- Decay heat removal (DHR) valves opened
- Decay heat passively removed via the steam generators and DHR heat exchangers to the reactor pool
- DHR system is composed of
  - four actuation valves (1 of 4 needed)
  - two heat exchangers (1 of 2 needed)
  - two independent single failure proof trains (1 of 2 trains needed)



NuScale Power™

Emergency Core Cooling System and Containment Heat Removal System

- Design does not require safety injection. Reactor water inventory is protected by containment isolation.
- Reactor vent valves opened on safety signal
- When containment liquid level is high enough, reactor recirculation valves open
- Decay heat removed
  - condensing steam on inside surface of containment vessel
  - convection and conduction through liquid and both vessel walls



NUSCALE POWER™

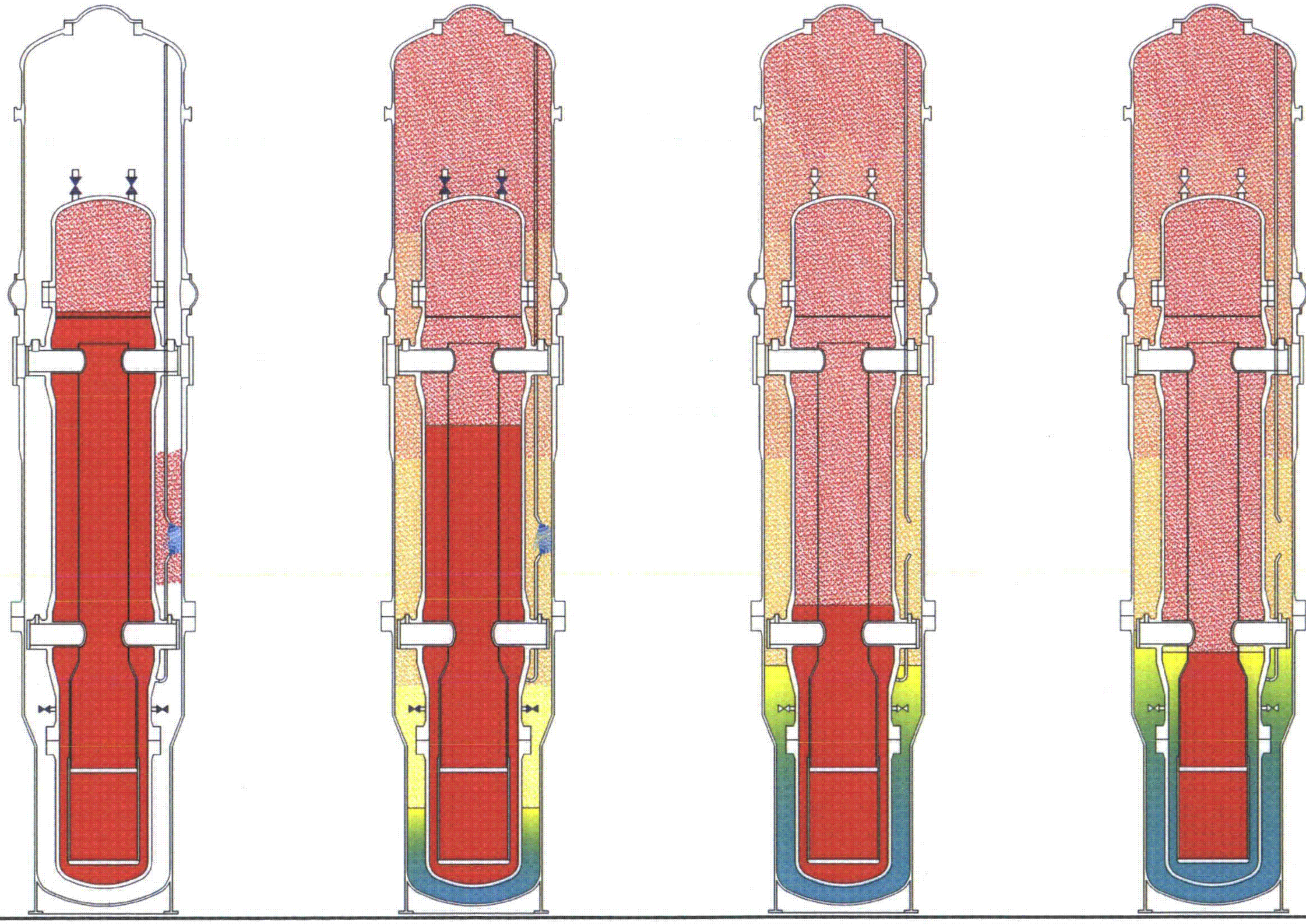
ECCS Accident Operation

Coolant escapes RPV (LOCA)

Condenses on CNV wall

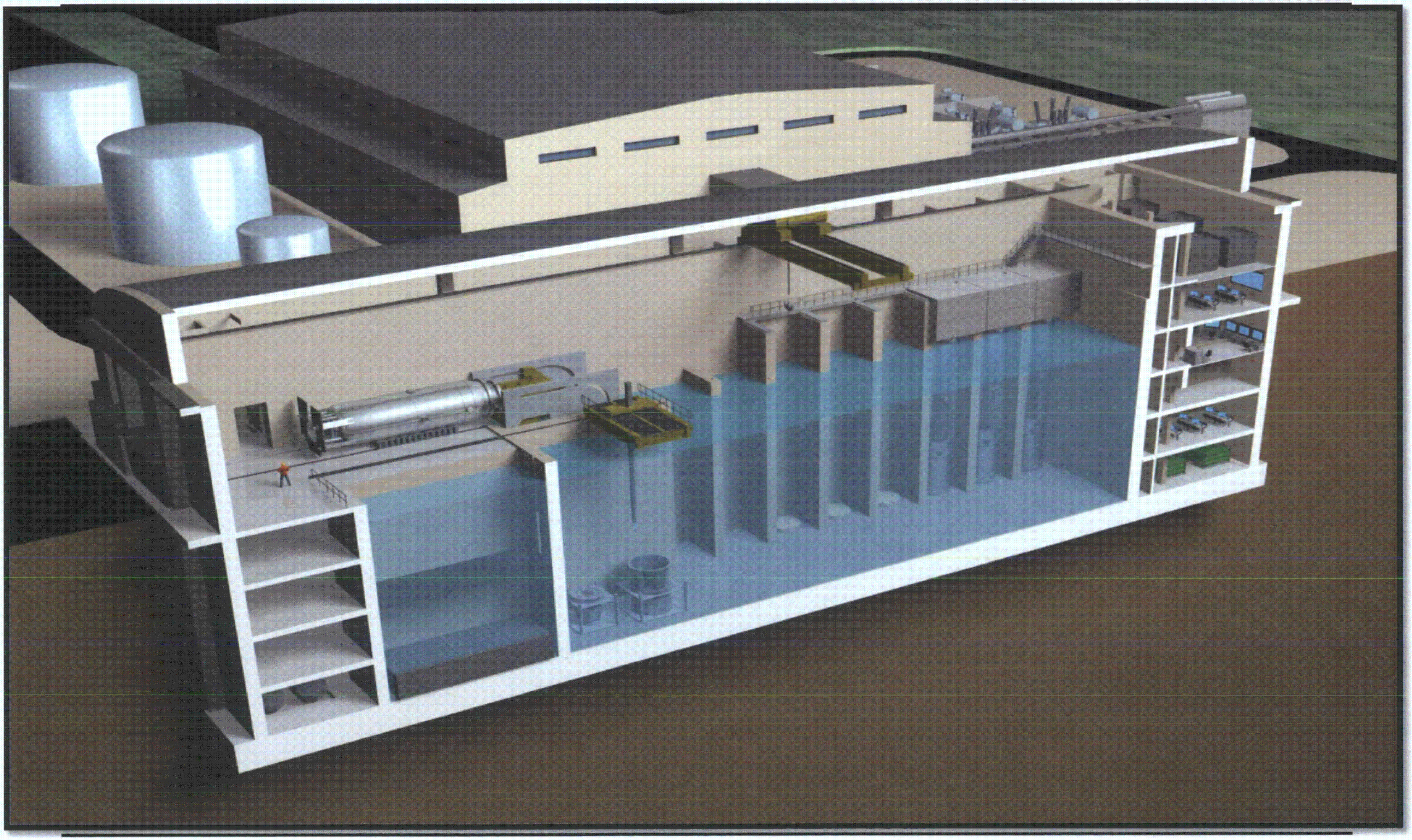
ECCS actuation

RPV level stabilizes



NuScale Power™

Module Component Assembly

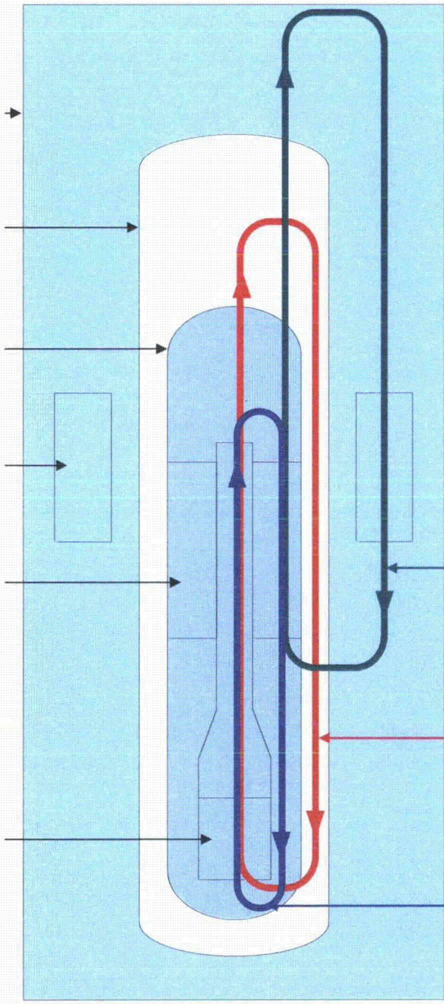


NuScale Power™

Design Simplification

- **New system**
  - containment evacuation
- **Eliminated systems**
  - containment spray
  - containment fan cooler
  - auxiliary feedwater
  - emergency core cooling system (ECCS) injection and recirculation
  - steam generator blowdown
  - main plant electrical generator hydrogen supply
- **Eliminated components**
  - reactor coolant pumps
  - ECCS pumps, tanks, and reactor pressure vessel (RPV) injection lines
  - containment sumps and tanks
  - refueling water storage tank
  - reactor coolant hot leg and cold leg piping
  - pressurizer surge line and relief tank
  - reactor vessel and primary coolant system insulation
  - safety-related emergency diesel generators

Passive Cooling Systems



- BC: boiling and condensation
- NC: natural circulation

- Boiling and condensation in the decay heat removal system
- Boiling and condensation in the emergency core cooling system
- Natural circulation in the reactor coolant system (RCS)

DHRS BC* transient operation

ECCS BC* accident operation

RCS NC* normal operation

NuScale Power™

Background

Background

- May 2012 meetings: Regulatory Gap Analysis
- July 2012 submittal: Gap Analysis Summary Report

{{

}}3(a)-(c)

- December 2012 meetings: Regulatory Gap Analysis
  - results: regulations requiring further consideration
  - EDS overview
- May 2013 Federal Register Notice: mPower DSRS issued for public comment

NuScale Power™

Background

- June 2013 meetings: NuScale Design-Specific Review Standard development
- August 2013 meetings: Design and SRP/DSRS information for NRC development of NuScale DSRS Chapters 7, 9, and 10
- November 2013 meetings: Design and SRP/DSRS information for NRC development of NuScale DSRS Chapter 5 and portions of Chapter 6

Unique NuScale Plant Features/Capabilities

- Features/capabilities informing electrical system design

{{

}}3(a)-(c)

Unique NuScale Plant Features/Capabilities

{{

}}3(a)-(c)

Unique NuScale Plant Features/Capabilities

{{

}}3(a)-(c)

Unique NuScale Plant Features/Capabilities

{{

}}3(a)-(c)

- the following slides depict a sequence of events for
  - loss-of-coolant accident
    - with electrical power available
    - with no electrical power available (whether AC or DC)
  - loss-of-feedwater (LOFW)
    - with electrical power available
    - with no electrical power available (whether AC or DC)

Ted Hough

NuScale Power™

Unique NuScale Plant Features/Capabilities

{{

}}3(a)-(c)

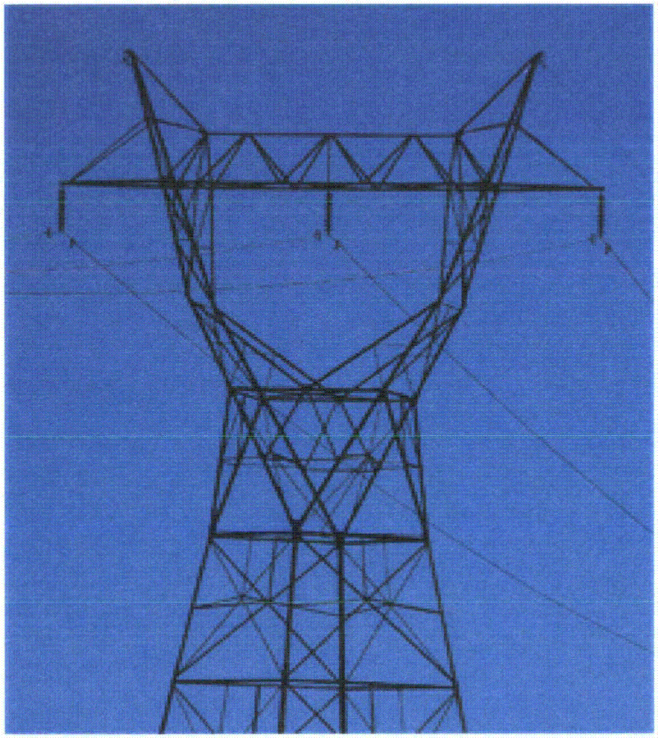
Unique NuScale Plant Features/Capabilities

{{

}}3(a)-(c)

NuScale Electrical System Design

- Overview of the NuScale electrical system design
- Additional detail provided in preliminary one-line diagrams
  - EHV
  - EMV



NuScale Power™

NuScale Electrical System Design

The Grid

{{

}}3(a)-(c)

NuScale Electrical System Design

- **On-Site AC (Main Distribution)**
  - EHV (13.8 kv) – {{ }}3(a)-(c)
  - EMV (4160 v) – {{ }}3(a)-(c)
  - ELV(480 v) – {{ }}3(a)-(c)
    - largest system in terms of number of loads
    - mostly motor loads
  - PL (lower voltage AC) – {{ }}3(a)-(c)
    - normal lighting and low power skid loads
    - both a power supply and load

NuScale Electrical System Design

- **On-Site AC (UPS and Back-Up Power)**
  - EDS (120 vac) – {{

    }}3(a)-(c)
  - EDN (120 & 208 vac) – {{

    }}3(a)-(c)
  - BDG
    - {{

      }} 3(a)-(c)

NuScale Electrical System Design

{{

}}3(a)-(c)

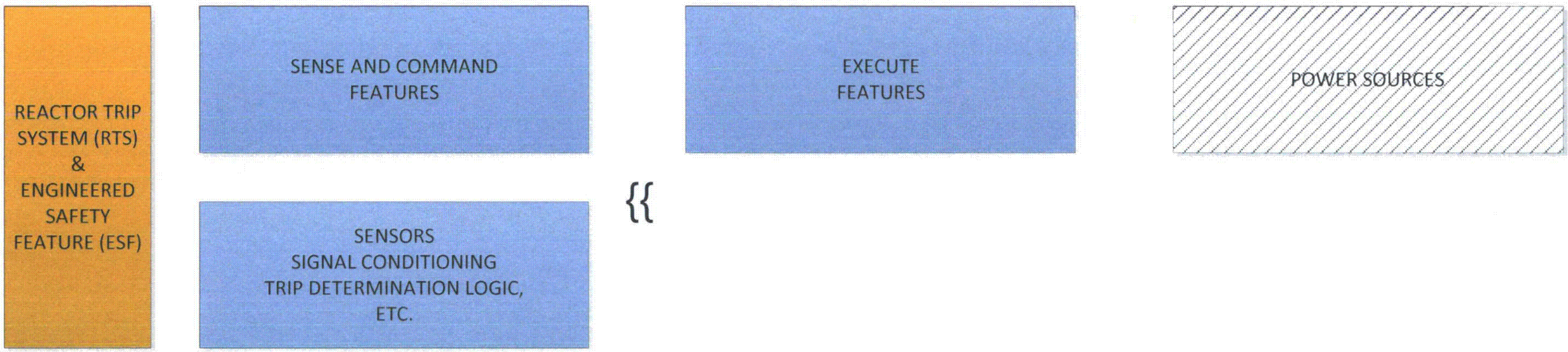
NuScale Electrical System Design

{{

}}3(a)-(c)

NuScale Electrical System Design

Sense and Command versus Execute



{{

}}3(a)-(c)

NuScale Power

NuScale Electrical System Design

{{

}}3(a)-(c)

Matt Featherston

NuScale Electrical System Design

- Implications
  - appropriate classification of electrical system SSCs

{{

}}3(a)-(c)

    - no safety-related emergency diesel generators

NuScale Power™

NuScale Electrical System Design

- Implications (cont.)

{{

}}3(a)-(c)

    - consistent with the NRC's policy documented in SECY 90-016, SECY 94-084, and SECY 95-132, and their associated Staff Requirements Memorandums (SRMs)
  - relevance of GDCs to the NuScale electrical design

Compliance with GDCs

- GDCs typically applied to nuclear power plant electrical systems
  - GDC 2, *Design bases for protection against natural phenomena*
  - GDC 4, *Environmental and dynamic effects design bases*
  - GDC 5, *Sharing of structures, systems, and components*
  - GDC 17, *Electric power systems*
  - GDC 18, *Inspection and testing of electric power systems*
  - GDCs 33, 34, 35, 38, 41, and 44, *Assurance of safety functions upon loss of offsite power*

Compliance with GDCs

- NuScale plant electrical power system design complies with relevant GDCs
  - exception – portion of GDC 17
  - relevance of GDCs and how they are applied differ from typical reactor designs due to unique advanced passive plant design

NuScale Power™

Compliance with GDCs

GDCs 2 and 4

- GDCs 2 and 4 govern the design of ITS SSCs to withstand natural phenomena and environmental/dynamic effects
- NuScale electrical design complies with GDCs 2 and 4
  - offsite power system – not applicable
  - onsite AC power system – applied to ITS SSCs
  - onsite DC power system – applied to ITS SSCs

Compliance with GDCs

GDCs 2 and 4 (cont.)

- **OFFSITE POWER SYSTEM – NOT APPLICABLE**
  - in December 2008, NEI transmitted a position paper regarding applicability of GDCs 2, 4, and 5 to the offsite power system (ML090060684)
  - the primary theme was that the offsite power system is not important to safety, and thus GDCs 2, 4, and 5 are not applicable to the offsite power system
  - the NRC concurred that GDCs 2 and 4 are not applicable to offsite power system (ML090260039)

Compliance with GDCs

GDCs 2 and 4 (cont.)

- **ONSITE AC POWER SYSTEM – APPLIED TO ITS SSCs**

{{

}}3(a)-(c)

Compliance with GDCs

GDCs 2 and 4 (cont.)

- **ONSITE DC POWER SYSTEM – APPLIED TO ITS SSCs**

{{

}}3(a)-(c)

NUSCALE POWER™

Compliance with GDCs

GDC 5

- GDC 5 governs the sharing of SSCs that are ITS
- NuScale electrical design complies with GDC 5
  - offsite power system – not applicable
  - onsite AC power system – applied to ITS SSCs
  - onsite DC power system – applied to ITS SSCs

Compliance with GDCs

GDC 5 (cont.)

- **OFFSITE POWER SYSTEM – NOT APPLICABLE**
  - the NuScale plant offsite power system is
    - not relied upon for the performance of safety functions
    - neither safety-related nor important to safety
  - the basis for concluding that GDCs 2 and 4 are not applicable to the offsite power system also supports a conclusion that GDC 5 is not applicable to an offsite power system that is not ITS
    - precedent
      - Dominion Energy, Inc. (Dominion), response to NRC Request for Additional Information (RAI) No. 08.02-42

Compliance with GDCs

GDC 5 (cont.)

- **ONSITE AC POWER SYSTEM – APPLIED TO ITS SSCs**

{{

}}3(a)-(c)

Compliance with GDCs

GDC 5 (cont.)

- **ONSITE DC POWER SYSTEM – APPLIED TO ITS SSCs**

{{

}}3(a)-(c)

Compliance with GDCs

GDC 18

- GDC 18 governs inspection and testing of electrical power system SSCs that are ITS
- NuScale electrical design complies with GDC 18
  - offsite power system – not applicable
  - onsite AC power system – applied to ITS SSCs
  - onsite DC power system – applied to ITS SSCs

Compliance with GDCs

GDC 18 (cont.)

- **OFFSITE POWER SYSTEM – NOT APPLICABLE**
  - the NuScale plant offsite power system is
    - not relied upon for the performance of safety functions
    - neither safety-related nor important to safety
  - the basis for concluding that GDCs 2 and 4 are not applicable to the offsite power system also supports a conclusion that GDC 18 is not applicable to an offsite power system that is not ITS
    - precedent
      - AP1000 Design Control Document, Table 8.1-1

Compliance with GDCs

GDC 18 (cont.)

- **ONSITE AC POWER SYSTEM – APPLIED TO ITS SSCs**

{{

}}3(a)-(c)

NUSCALE POWER™

Compliance with GDCs

GDC 18 (cont.)

- **ONSITE DC POWER SYSTEM – APPLIED TO ITS SSCs**

{{

}}3(a)-(c)

Compliance with GDCs

GDCs 33, 34, 35, 38, 41, and 44

- Contain criteria for safety systems, including electrical "redundancy provisions"
- These "redundancy provisions" are applied to
  - reactor coolant makeup during small breaks (GDC 33)
    - alternative principal design criterion to GDC 33
  - residual heat removal (GDC 34)
  - emergency core cooling (GDC 35)
  - containment heat removal (GDC 38)
  - containment atmosphere cleanup (GDC 41)
  - cooling water for SSCs important to safety (GDC 44)

NuScale Power™

Compliance with GDCs

GDCs 33, 34, 35, 38, 41, and 44 (cont.)

- The redundancy provisions of these criteria are satisfied for a typical reactor design by demonstrating that the minimum design provisions of GDC 17 are met

{{

}}3(a)-(c)

NuScale Power™

Compliance with GDCs

GDC 17

{{

}}3(a)-(c)

Compliance with GDCs

GDC 17 (cont.)

Synopsis of GDC 17 Criterion	Excerpt of GDC 17 Criterion
Provisions to include both an offsite and onsite power system shall be provided, each independent of the other and capable of providing power for all safety functions	An onsite electric power system and an offsite electric power system shall be provided to permit functioning of structures, systems, and components important to safety. The safety function for each system (assuming the other system is not functioning) shall be to provide sufficient capacity and capability to assure that (1) specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded as a result of anticipated operational occurrences and (2) the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents.
Provisions assuring sufficient independence, redundancy, and testability	The onsite electric power supplies, including the batteries, and the onsite electric distribution system, shall have sufficient independence, redundancy, and testability to perform their safety functions assuming a single failure.
Two physically independent offsite power circuits with specified design provisions to ensure safety functions are accomplished	Electric power from the transmission network to the onsite electric distribution system shall be supplied by two physically independent circuits (not necessarily on separate rights of way) designed and located so as to minimize to the extent practical the likelihood of their simultaneous failure under operating and postulated accident and environmental conditions. A switchyard common to both circuits is acceptable. Each of these circuits shall be designed to be available in sufficient time following a loss of all onsite alternating current power supplies and the other offsite electric power circuit, to assure that specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded. One of these circuits shall be designed to be available within a few seconds following a loss-of-coolant accident to assure that core cooling, containment integrity, and other vital safety functions are maintained.
Provisions to minimize the probability of losing electric power	Provisions shall be included to minimize the probability of losing electric power from any of the remaining supplies as a result of, or coincident with, the loss of power generated by the nuclear power unit, the loss of power from the transmission network, or the loss of power from the onsite electric power supplies.

Compliance with GDCs

GDC 17 (cont.)

Synopsis of GDC 17 Criterion	Points of Consideration for NuScale Design
Provisions to include both an offsite and onsite power system shall be provided, each independent of the other and capable of providing power for all safety functions	•{{ }}3(a)-(c)

NuScale Position on Relevance/Applicability

{{ }}3(a)-(c)

NuScale Power™

Compliance with GDCs

GDC 17 (cont.)

Synopsis of GDC 17 Criterion	Points of Consideration for NuScale Design
Provisions assuring sufficient independence, redundancy, and testability	•{{ }}3(a)-(c)

NuScale Position on Relevance/Applicability

{{

}}3(a)-(c)

NuScale Power™

Compliance with GDCs

GDC 17 (cont.)

Synopsis of GDC 17 Criterion	Points of Consideration for NuScale Design
Two physically independent offsite power circuits with specified design provisions to ensure safety functions are accomplished	{{

}}3(a)-(c)

NuScale Position on Relevance/Applicability

Departure warranted

- underlying purpose satisfied by the NuScale design without providing two physically independent transmission circuits
- departure consistent with the Commission's policy for passive plants, as documented in SECY-94-084 and SECY-95-132 and their associated SRMs

NuScale Power™

Compliance with GDCs

GDC 17 (cont.)

Synopsis of GDC 17 Criterion	Points of Consideration for NuScale Design
Provisions to minimize the probability of losing electric power	{{

}}3(a)-(c)

NuScale Position on Relevance/Applicability

{{

}}3(a)-(c)

NuScale Power™

Compliance with GDCs

GDC 17 – SIGNIFICANT CONSIDERATIONS FOR DSRS

- **Departure(s) from GDC 17**
  - only one offsite transmission circuit

{{

}}3(a)-(c)

PM-0214-6098-NP

NuScale Power™

Compliance with GDCs

Summary of GDC Relevance to NuScale Design

General Design Criterion	Relevance of GDC to		
	Section 8.2 Offsite Power System	Section 8.3.1 Onsite AC Power System	Section 8.3.2 Onsite DC Power System
GDC 2	NA	ITS only	ITS only
GDC 4	NA	ITS only	ITS only
GDC 5	NA	ITS only	ITS only
GDC 17	NA – two physically independent transmission circuits {{ }}3(a)-(c)	{{ }}3(a)-(c)	{{ }}3(a)-(c)
GDC 18	NA	ITS only	ITS only
GDCs 33, 34, 35, 38, 41, and 44 (via GDC 17)	NA	NA	NA

NuScale Power™

Compliance with 10 CFR 50.63

- **10 CFR 50.63 (SBO rule) requires each nuclear power plant to**
  - specify an SBO coping duration
  - demonstrate the capability to cope for the specified duration

Compliance with 10 CFR 50.63

NuScale Coping Duration – Minimum 72 Hours

- SBO coping duration based on
  - site- and plant-specific factors that contribute to the likelihood of and capability for restoring AC power following an SBO
  - consideration for redundancy and reliability of onsite emergency AC (EAC) power sources
- Passive plants do not have EAC power sources, and thus meet the 10 CFR 50.63 requirements for coping duration by ensuring safety-related functions for a minimum of 72 hours following an SBO event
- The minimum 72-hour coping duration for passive plant designs is consistent with the station blackout duration approved by the NRC staff for the AP1000 design, as reflected in SECY-94-084

NuScale Power™

Compliance with 10 CFR 50.63

Demonstrating 72-Hour Coping Capability –

{{ }}3(a)-(c)

{{

}}3(a)-(c)

- The NuScale plant design conforms to Regulatory Guide 1.155, except for portions that are not relevant to passive plant designs as clarified by SECY-94-084 and SECY-95-132, and their associated Staff Requirements Memorandums

Compliance with 10 CFR 50.63

Station Blackout Mitigation Strategies Rulemaking – 10 CFR 50.63 Amendment

- Incorporates into 10 CFR 50 the mitigating strategies of Order EA-12-049 and other requirements from the Fukushima Daiichi lessons learned (ML13077A453)
  - anticipated to result in changes to 10 CFR 50.63, and perhaps a new section under 10 CFR 50, to include new requirements for mitigating the following resulting from beyond-design-basis external events
    - extended loss of AC power (ELAP)
    - loss of normal access to the ultimate heat sink (LUHS)

Compliance with 10 CFR 50.63

Station Blackout Mitigation Strategies Rulemaking – 10 CFR 50.63 Amendment

{{

}}3(a)-(c)

NuScale Power™

NuScale DSRS Chapter 8

{{

}}3(a)-(c)

PM-0214-6098-NP

NUSCALE POWER™

NuScale DSRS Chapter 8

SRP/DSRS INFORMATION

- Current NuScale assessment for each section is as indicated in overview table on previous slide
- As appropriate, NuScale Gap Analysis to be revised to reflect current assessment
- Information for NRC development of NuScale DSRS
  - NuScale design information
  - NuScale comments on mPower DSRS
  - NuScale Gap Analysis and updates thereto
  - as available, results of GDC 17 assessment

Results Achieved and Path Forward

- Provided information for development of NuScale DSRS for Chapter 8
  - design information
  - SRP/DSRS information
- Plan for future interactions

6650 SW Redwood Lane, Suite 210
Portland, OR 97224
503.715.2222

1100 NE Circle Blvd., Suite 200
Corvallis , OR 97330
541.360.0500

11333 Woodglen Ave., Suite 205
Rockville, MD 20852
301.770.0472

http://www.nuscalepower.com