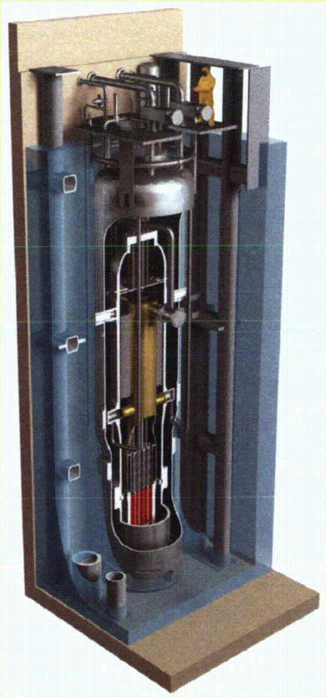
Containment Design



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Reactor Module Design Engineer

June 5, 2013

Nonproprietary

NuScale Power™

NP-PM-0413-3641-NP

Agenda

- Purpose
- Plant overview
- Background
- Chapter 6 Standard Review Plan sections applicability to NuScale design
- Key Chapter 6 Standard Review Plan sections
- Results achieved and next steps

Purpose

- Inform the NRC of details of containment design
- Discuss regulatory gap analysis results related to containment
- Discuss design-specific review standard (DSRS) development for Chapter 6

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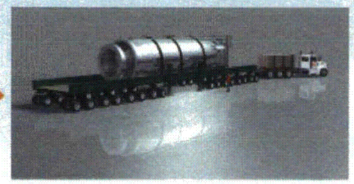
Plant Overview

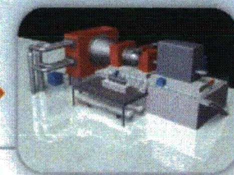
Factory Manufacturing

Module includes Containment and Reactor Vessel

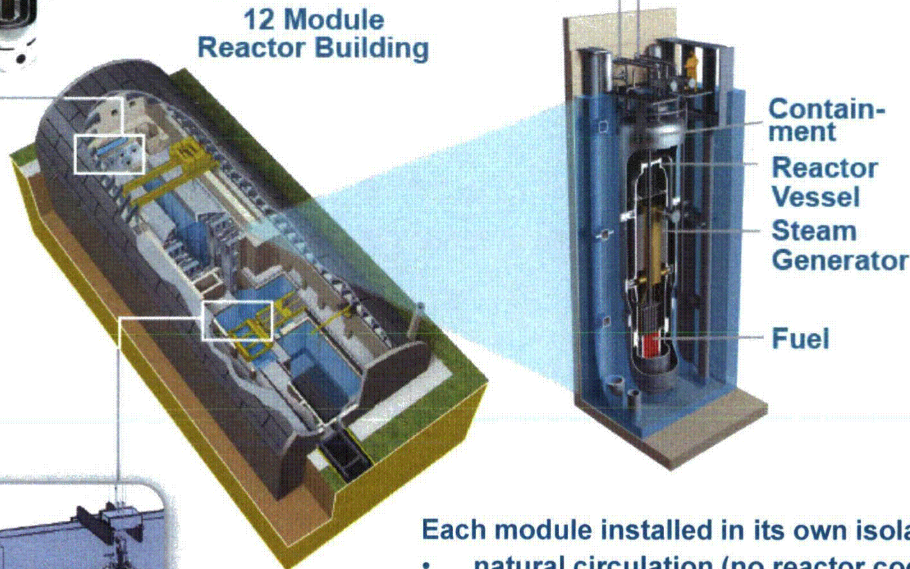
Shipped by Truck, Rail, or Barge



Skid-Mounted Steam Turbine/Generator

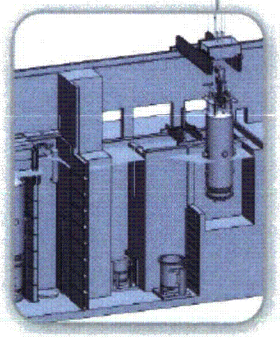


Below-Ground Control Room provides enhanced security and state-of-the-art controls



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

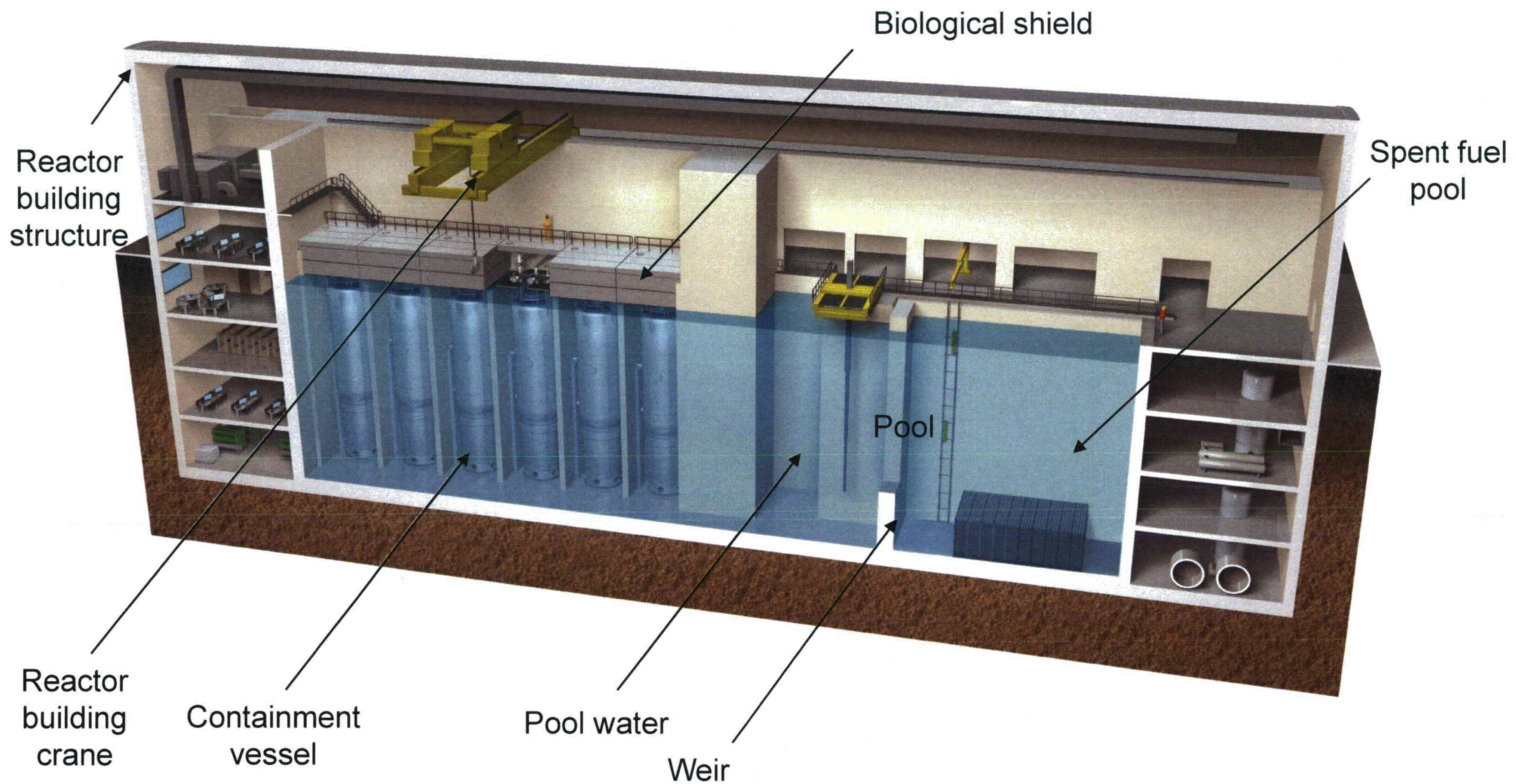
- **natural circulation (no reactor coolant pumps)**
- **37 standard 17x17 PWR fuel (half-height) fuel assemblies**
- **standard magnetic jack control rod drives**
- **internal helical coil steam generators and pressurizer**
- **45 MWe net power**

Design Simplification

Eliminated Systems	Eliminated Components
Containment spray	Reactor coolant pumps
Containment fan cooler	Emergency core cooling system pumps and tanks
Steam generator blowdown	Containment sumps
Auxiliary feedwater	Refueling water storage tank
	Reactor coolant piping
	Pressurizer relief tank
	Reactor vessel and primary coolant system insulation
	Safety-related emergency diesel generators

Reactor Building

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



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

Seismically robust

- system submerged in a below-ground pool of water in an earthquake-resistant building
- reactor pool attenuates ground motion and dissipates energy

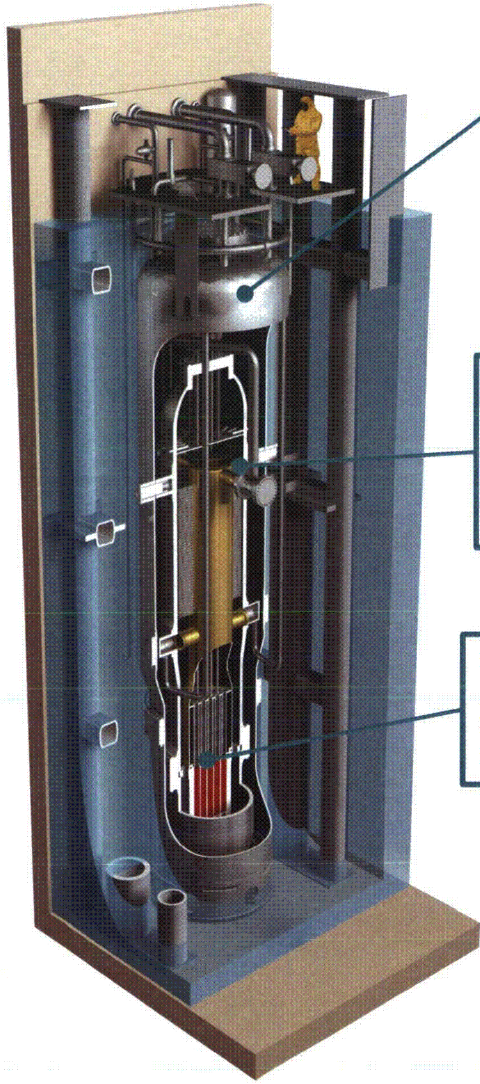
Simple and small

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

Defense-in-depth

- multiple additional barriers to protect against the release of radiation to the environment

45 MWe Reactor Module

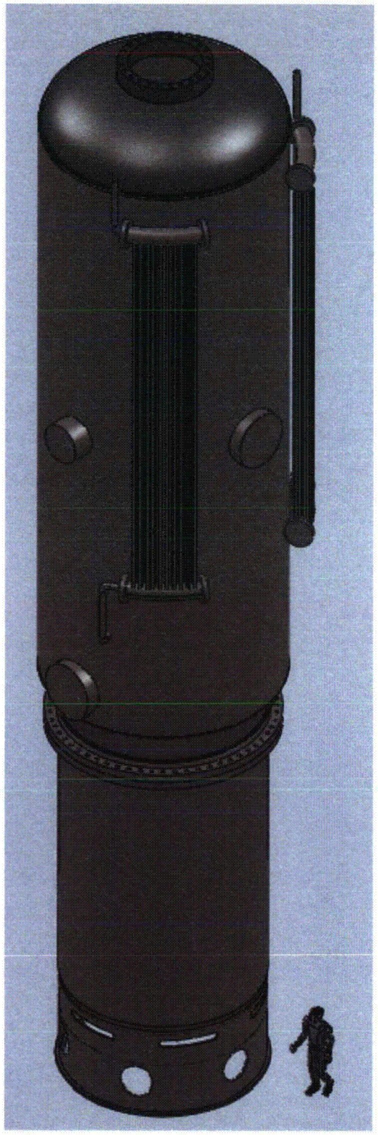


Steel containment *12 times pressure* of typical PWR containment

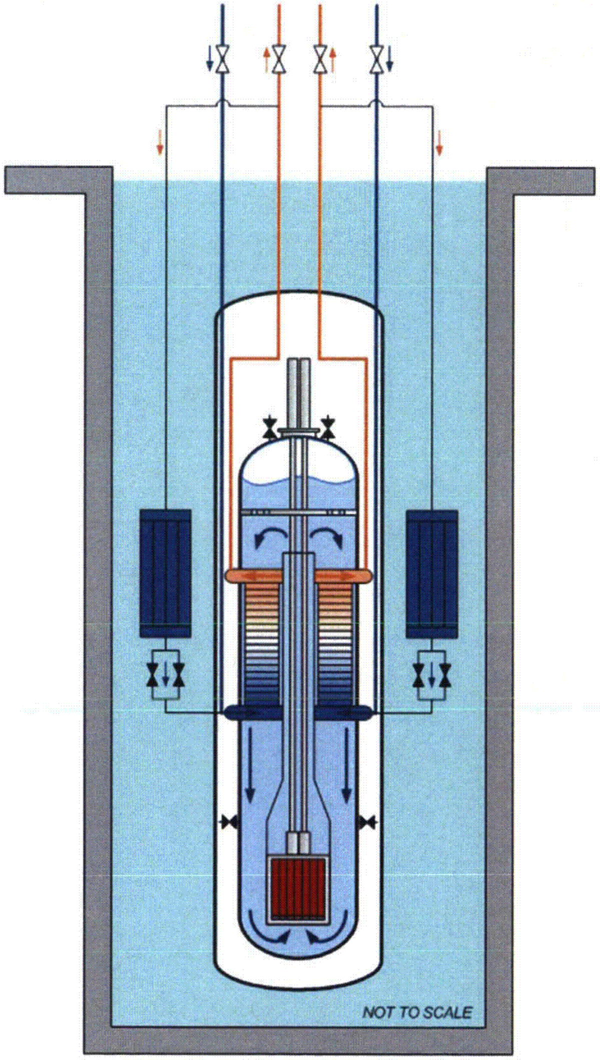
Water volume-to-thermal power ratio is *four times larger resulting in better cooling*

Reactor core has *only five percent of the fuel* of a large reactor

Passive Decay Heat Removal System



- Main steam and main feedwater isolated
- Decay heat removal (DHR) isolation valves opened
- Decay heat passively removed via the steam generators and DHR heat exchangers to the reactor pool



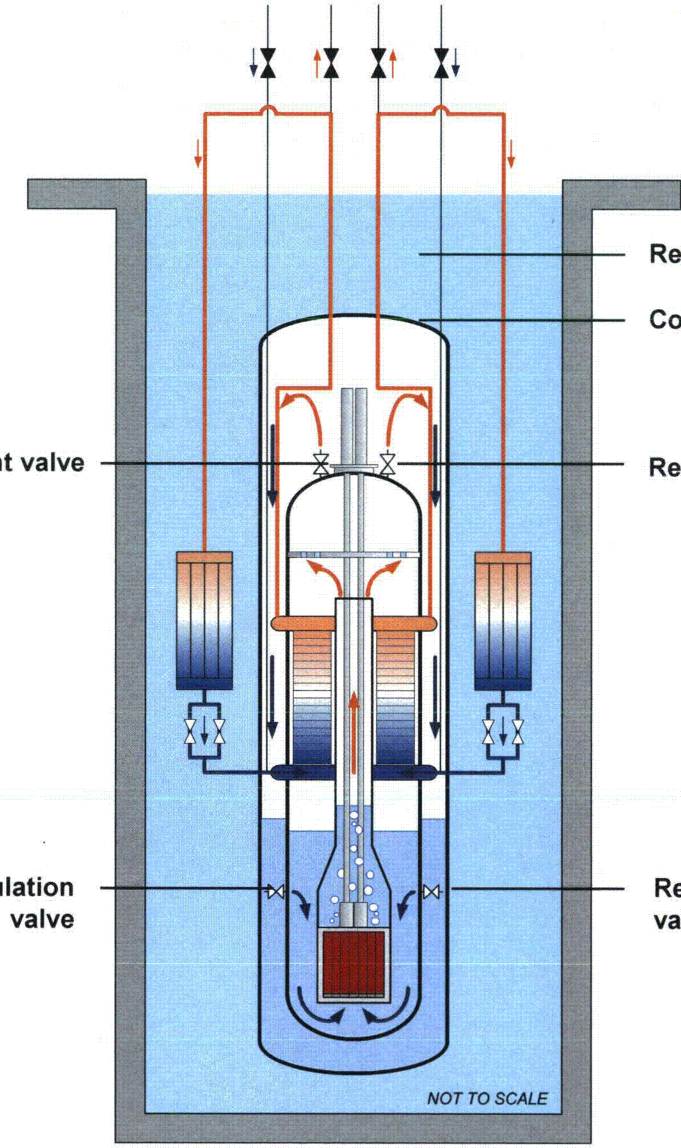
Emergency Core Cooling System/Containment Heat Removal

Reactor vent valves opened on safety signal

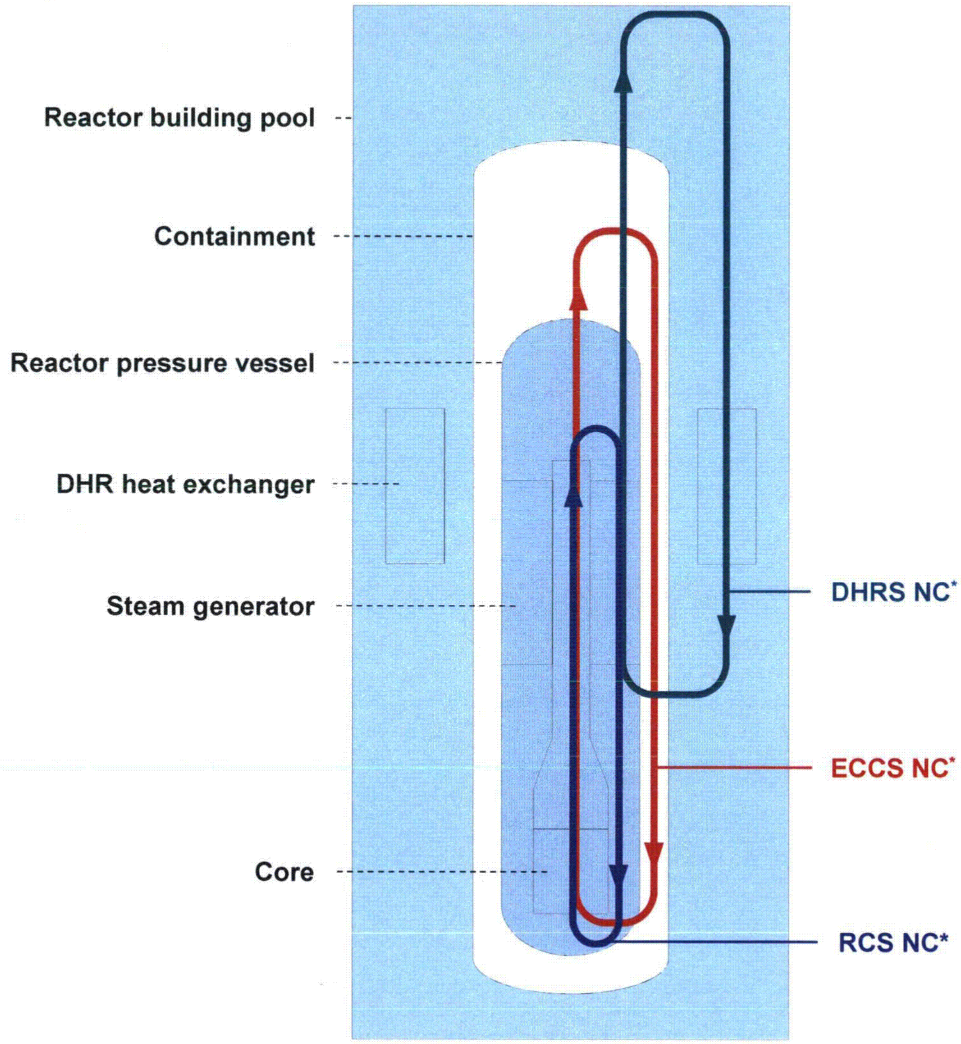
When containment liquid level is high enough, reactor recirculation valves open

Decay heat removed

- condensing steam on inside surface of containment vessel
- convection and conduction through liquid and both vessel walls



Plant Overview—Natural Circulation



* NC: natural circulation

- Natural circulation in the decay heat removal system (DHRS)
- Natural circulation in the emergency core cooling system (ECCS)
- Natural circulation in the reactor coolant system (RCS)

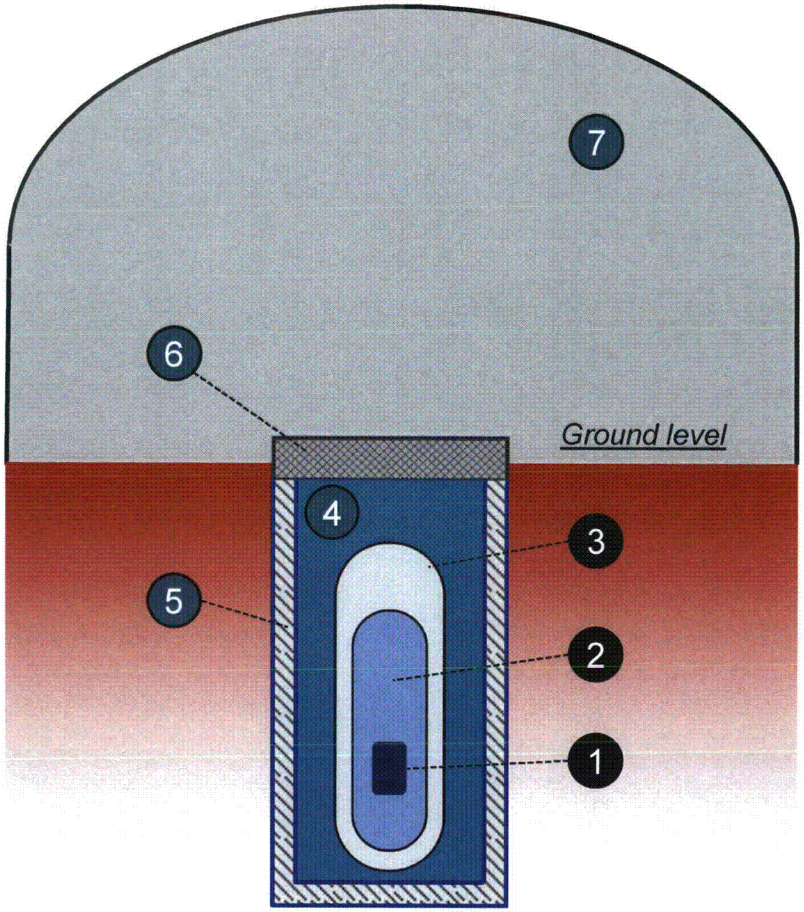
Barriers between Fuel and Environment

Conventional designs

1. Fuel pellet and cladding
2. Reactor vessel
3. Containment

Additional features in NuScale design

4. Water in reactor building pool
5. Stainless steel-lined concrete reactor pool
6. Biological shield covers each reactor
7. Reactor building (Seismic Category I)

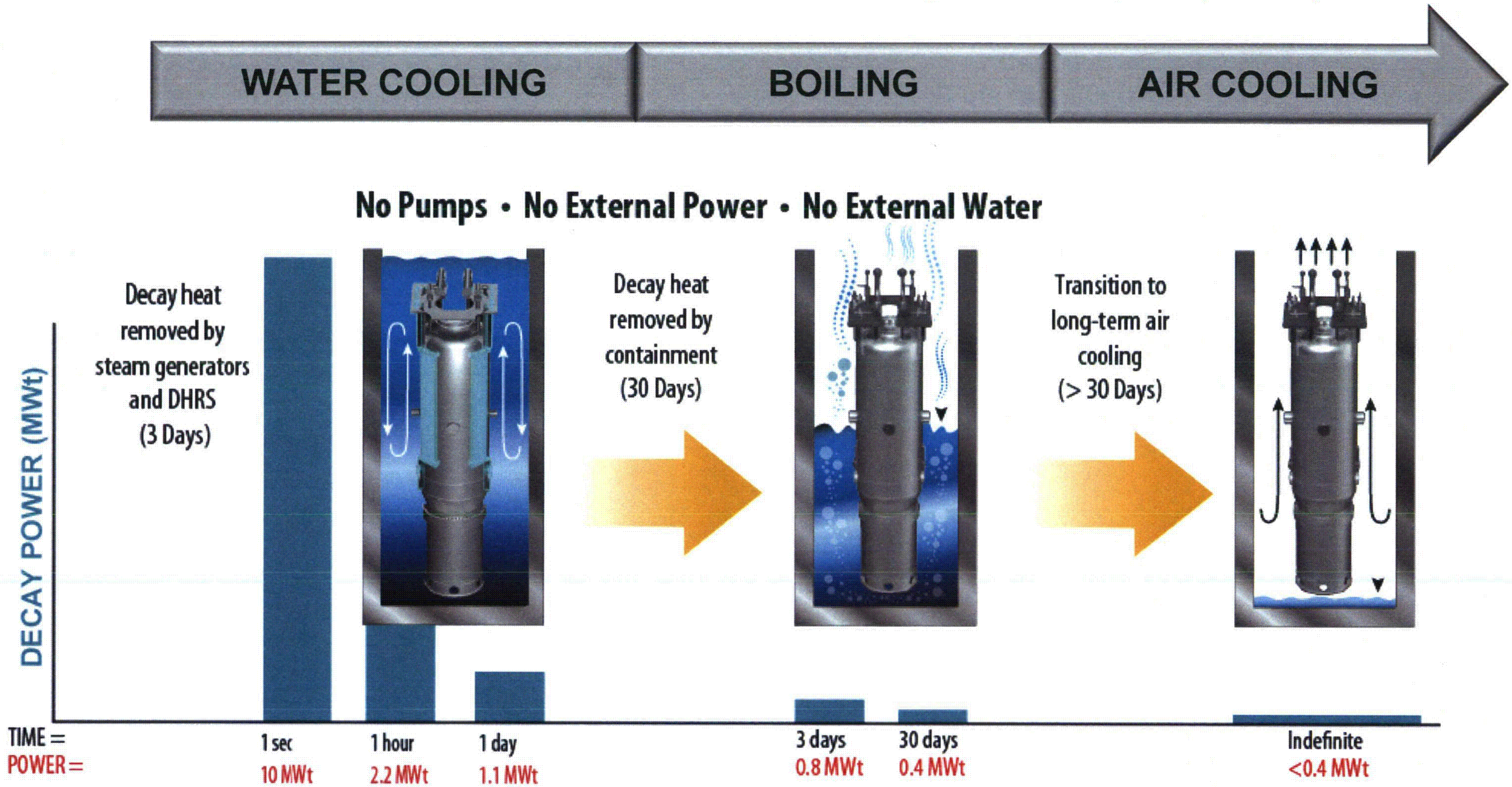


Major Breakthrough in Safety

- NuScale design has achieved the "Triple Crown" of nuclear plant safety. The plant can safely shut down and self-cool indefinitely with
  - no operator action
  - no AC or DC power
  - no additional water
- Safety valves align in their safest configuration on loss of all plant power
- Core cooling and containment integrity maintained with no AC or DC power
- Water level is maintained above the core in the hydraulically coupled containment and reactor vessel design

Stable, Long-Term Cooling Under All Conditions

Reactor and nuclear fuel cooled indefinitely without pumps or power



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Background

- July 2012 meeting—containment functional requirements
  - heat transfer-related functional requirements
  - pressure and fission product containment
  - other functional requirements

- December 2012 Meeting—regulations requiring further consideration
  - 10 CFR 50.44(c)(2) —Combustible Gas Control

Chapter 6 Standard Review Plan Sections Applicability to NuScale Design

Chapter 6 SRP Sections Applicability to NuScale Design

SRP Number	SRP Title	Applicability to NuScale Design	Meeting Date (proposed)	Comments
6.2.1.1.A	PWR Dry Containments, Including Subatmospheric Containments	Significant change to SRP or new SRP language	June 2013	Design details to be provided in the form of a slide presentation and associate figures and drawings
6.2.1.2	Subcompartment Analysis	Not applicable		NuScale design does not include subcompartments
6.2.1.3	Mass and Energy Release Analysis for Postulated Loss-of-Coolant Accidents (LOCAs)	Partially applicable	December 2013	• App K feature list contains features that are not applicable to the NuScale design • No exemption from the App K requirements is contemplated
6.2.1.5	Minimum Containment Pressure Analysis for Emergency Core Cooling System Performance Capability Studies	Not applicable		NuScale design ECCS operation is not affected by containment pressure
6.2.2	Containment Heat Removal Systems	Significant change to SRP or new SRP language	September 2013	NuScale design utilizes passive heat removal through the containment walls
6.2.3	Secondary Containment Functional Design	Not applicable		NuScale design does not include a secondary containment
6.2.4	Containment Isolation System	Significant change to SRP or new SRP language	September 2013	The NuScale program for containment isolation is under development
6.2.5	Combustible Gas Control in Containment	Partially applicable	June 2013	
6.2.6	Containment Leakage Testing	Significant change to SRP or new SRP language	Q1 2014	The NuScale program for containment leakage testing is expected to the subject of a future NRC meeting

Chapter 6 SRP Sections Applicability to NuScale Design

SRP Number	SRP Title	Applicability to NuScale Design	Meeting Date (proposed)	Comments
6.2.7	Fracture Prevention of Containment Pressure Boundary	Significant change to SRP or new SRP language	June 2013	The NuScale containment vessel will be subject to considerably higher fluence than a typical LLWR containment vessel
6.3	Emergency Core Cooling System	Significant change to SRP or new SRP language	September 2013	The NuScale ECCS design is significantly different from other reactor ECCS systems
6.4	Control Room Habitability System	Partially applicable	Q1 2014	
6.5	Containment Atmosphere	Not applicable	September 2013	
6.5.1	ESF Atmosphere Cleanup Systems	Not applicable	September 2013	
6.5.2	Containment Spray as a Fission Product Cleanup System	Not applicable	September 2013	
6.5.3	Fission Product Control Systems and Structures	Not applicable	September 2013	
6.5.4	Ice Condenser as Fission Product Cleanup System	Not applicable		
6.5.5	Pressure Suppression Pool as a Fission Product Cleanup System	Not applicable		
6.6	ISI and Testing of Class 2 and 3 Components	Applicable	Q1 2014	
6.7	MSIV Leakage Control System (BWR)	Not applicable		NuScale is a PWR

Key Chapter 6 Standard Review Plan Sections

Focus

- 6.2.1.1.A PWR Dry Containments, Including Subatmospheric Containments
- 6.2.5 Combustible Gas Control in Containment
- 6.2.7 Fracture Prevention of Containment Pressure Boundary

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Containment Design – SRP

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Presentation Topics

- Containment vessel design approach
  - design and operating conditions
  - preliminary sizing
  - weld locations and material selection
- Cladding of inside and outside surfaces
- Access ports
- Reactor module (RXM) and containment vessel (CNV) support system
- Containment head penetrations

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Containment Design

- The containment vessel is a Class MC (metal containment) component but will be constructed and stamped as a Class 1 vessel
  - ASME Section III, Subsection NCA 2134(c), permits construction and stamping as a Class 1 vessel with overpressure protection in accordance with Article NE-7000

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Overview of Containment Vessel Assembly

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Containment Vessel Design and Operating Parameters

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Preliminary Sizing

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Containment Vessel Material Selection

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Containment Vessel Weld Locations

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Metal Mass

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Containment Vessel Surface Cladding

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Containment Vessel Support System

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Containment Vessel Head Openings

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Feedwater and Main Steam Isolation Valves

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Access for Repair, Maintenance, and Inservice Inspections

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Combustible Gas Control (SRP 6.2.5)

Presentation Topics

- 10 CFR 50.44(c) requirements
- NuScale position
- Severe accident scenario
  - H_2-O_2-steam generation
  - 100% fuel cladding coolant interaction
  - Detonation and deflagration pressure

10 CFR 50.44(c) Requirements

- Mixed atmosphere
  - capability for ensuring a mixed atmosphere
- Combustible gas control
  - inerted atmosphere, or
  - limit hydrogen concentration to < 10% (volume)
- Equipment survivability (for containments that do not rely on inerted atmosphere)
  - survivability of monitoring equipment and other SSC (during and after H_2 burn)
  - H_2 detonations must be included unless shown to be highly unlikely

Inerted atmosphere: containment atmosphere with < 4% O_2 by volume

10 CFR 50.44(c) Requirements

- Monitoring
  - O_2 monitors for inerted atmosphere
  - H_2 monitors for measuring concentration
- Structural analysis
  - 100% fuel clad-coolant interaction generating H_2 and steam
  - H_2 release, accumulation and burn scenario
  - Systems necessary to ensure containment integrity must be analyzed
    - Regulatory Guide 1.216 provides guidance on analysis procedure and metrics

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NuScale Position

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Severe Accident

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Severe Accident

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Severe Accident

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Severe Accident

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Severe Accident

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Fracture Prevention
(SRP 6.2.7)

Regulatory Requirements

- 10 CFR 50, Appendix A
  - GDC 1: Quality Standards and Records
  - GDC 16: Containment Design
    - Prevention of radioactive release
  - GDC 50: Containment Design Basis
  - GDC 51: Fracture Prevention of Containment Pressure Boundary
    - Material behaves in nonbrittle manner and rapidly propagating fracture is minimized
- 10 CFR 50, Appendix G, Fracture Toughness Requirements
- 10 CFR 50.61, Protection Against Pressurized Thermal Shock

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Fracture Toughness Considerations

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Reactor Pressure Vessel and Containment Vessel 54 Effective Full-Power Year Fluence

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Containment Vessel 54 Effective Full-Power Year Fluence

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54 Effective Full-Power Year Containment Vessel Pressurized Thermal Shock

- Screening criterion
  - 10 CFR 50.61, “Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events”

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*Typical RT_{NDT} for SA-508, Grade 3, Class 1	
• Range	-67°F to -22°F
• At T/4 average	-31°F

T/4 = One-quarter of shell thickness

Fracture Toughness Considerations

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Preliminary Design Surveillance Program

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Results Achieved and Next Steps

- Results achieved
  - Chapter 6 DSRS information outstanding
    - agreements made
    - future information requirements
  - Basis for future discussion
    - Understanding of the containment vessel design
      - current design
      - decisions to be made
- Specific subjects for future meetings

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