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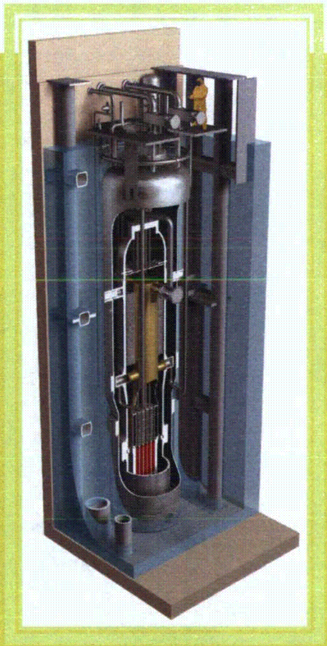
Fuel Design Methodology



Larry Linik

December 6, 2012

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Agenda

- Purpose of the meeting
- Background
- Plant overview
- Fuel design team
- Schedule implications

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- Design-Specific Review Standard for DCD Section 4.2
- Feedback and next steps

Purpose of the Meeting

- Describe fuel code methodology
  - Present {{ }}3(a) code to NRC
- Present design team to NRC
- Communicate status of fuel design activities
  - Current status
  - Upcoming activities
- Open the discussion for DSRS on DCD Section 4.2
- NRC feedback on the NuScale approach leading to agreement on path for Design Certification

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Background

Review of Topics from the May Meeting

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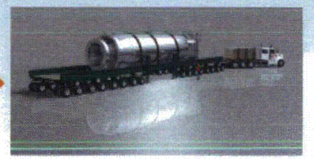
Plant Overview

Factory Manufacturing

Module includes Containment and Reactor Vessel

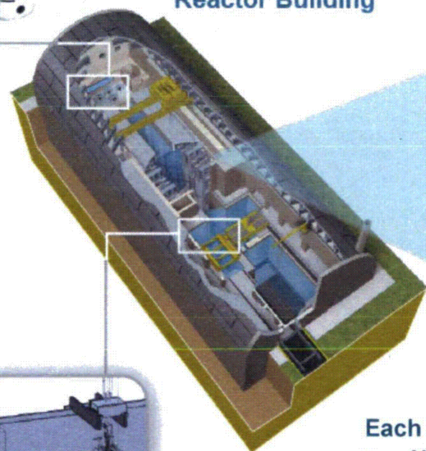
Shipped by Truck, Rail, or Barge

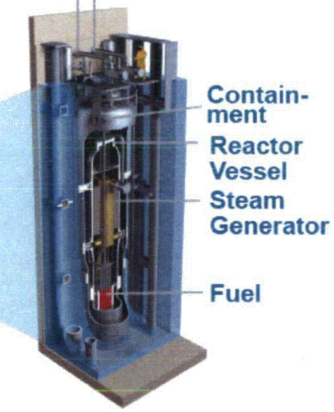


Skid-Mounted Steam Turbine/Generator

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

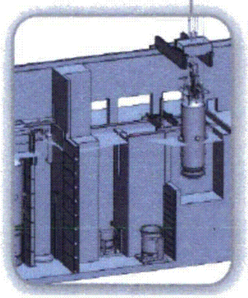
12 Module Reactor Building





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

- Refueled once every 24 months
- 10 Day Refueling Target

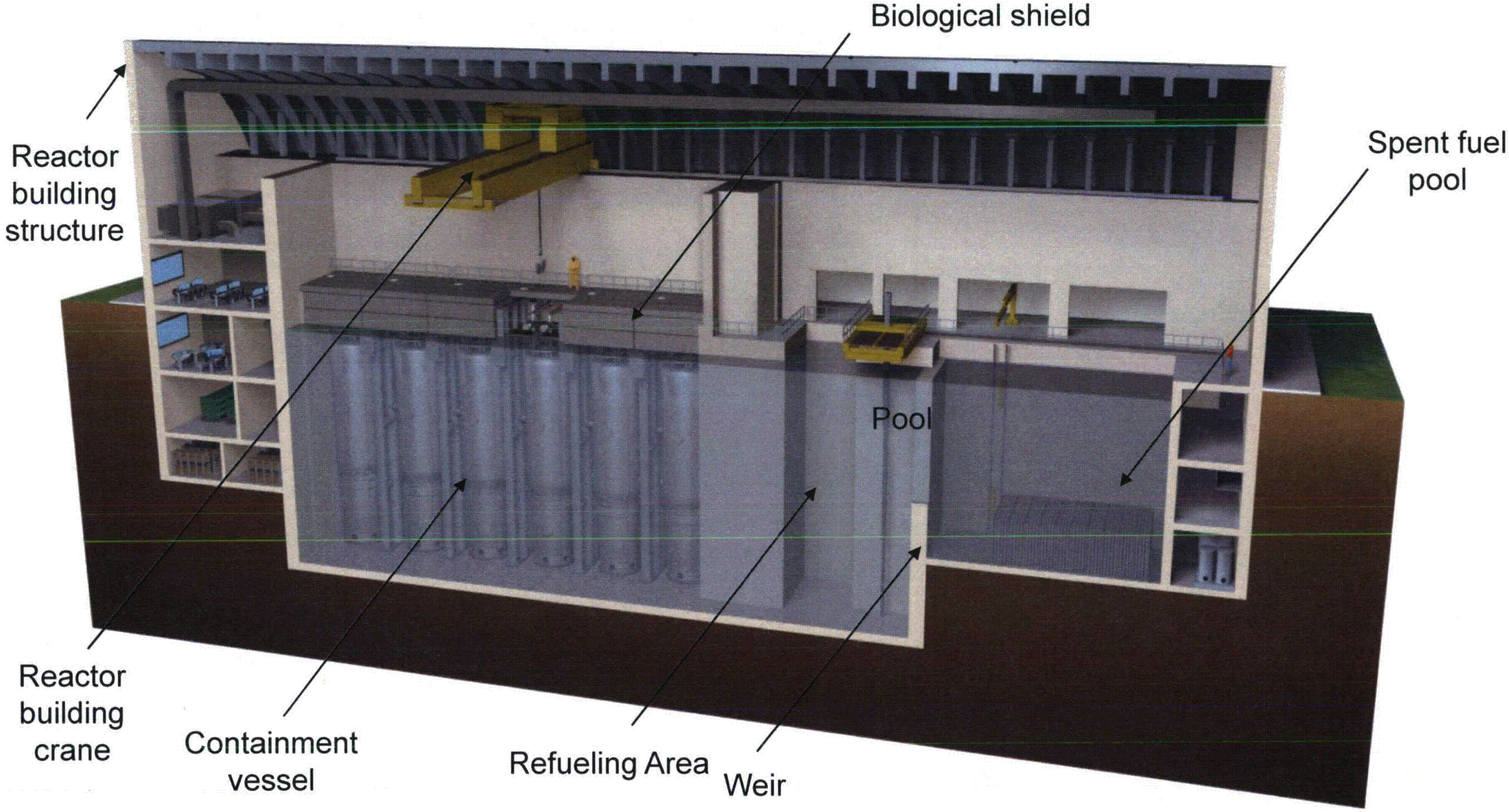


Each Module installed in its own isolated bay

- **Natural Circulation (No Reactor Coolant Pumps**
- **Standard 17x17 PWR Fuel**
- **Standard Magnetic Jack Control Rod Drives**
- **Internal Steam Generator and Pressurizer**
- **45 MWe Net Power**

Reactor Building

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



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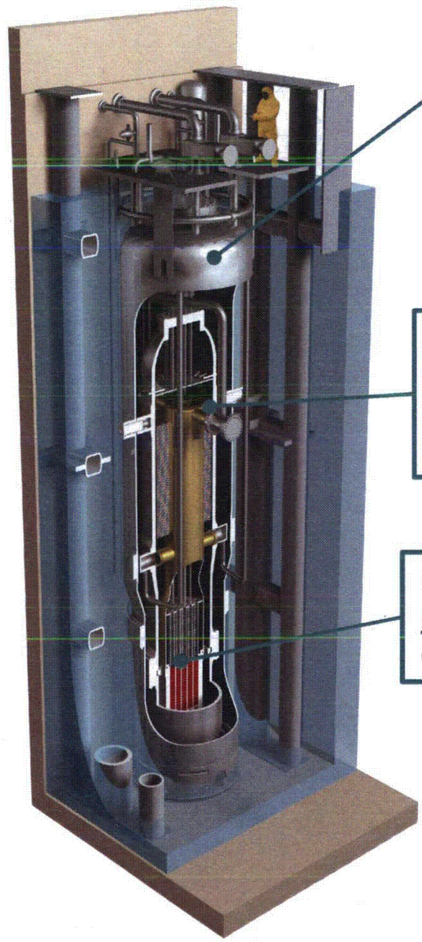
Reactor Module Overview

- 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
- 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



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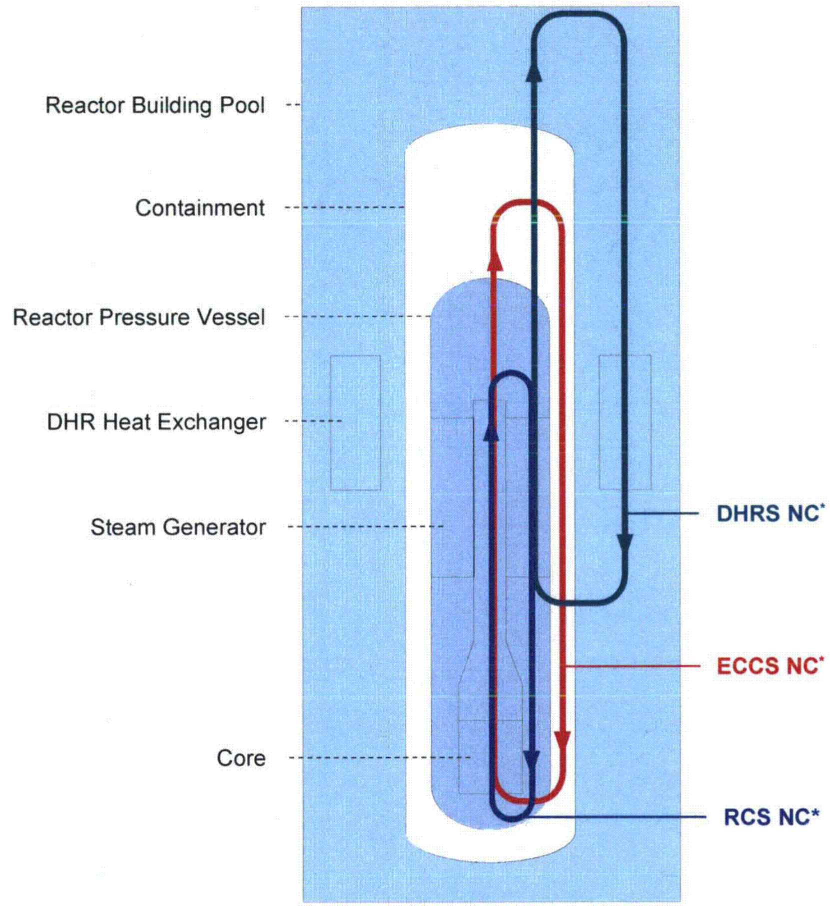
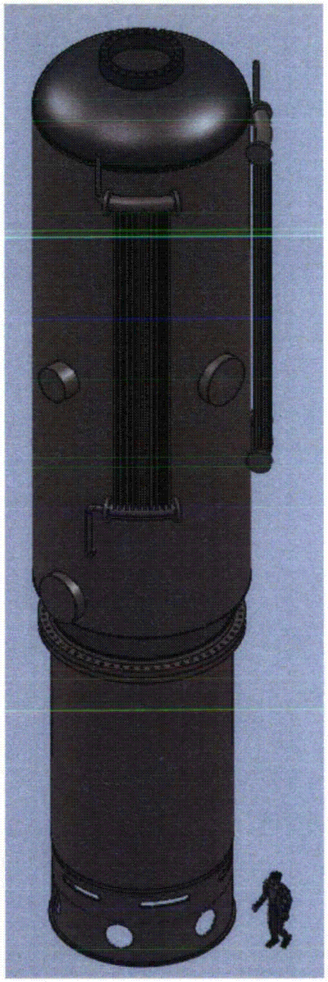
Plant Overview – Natural Circulation



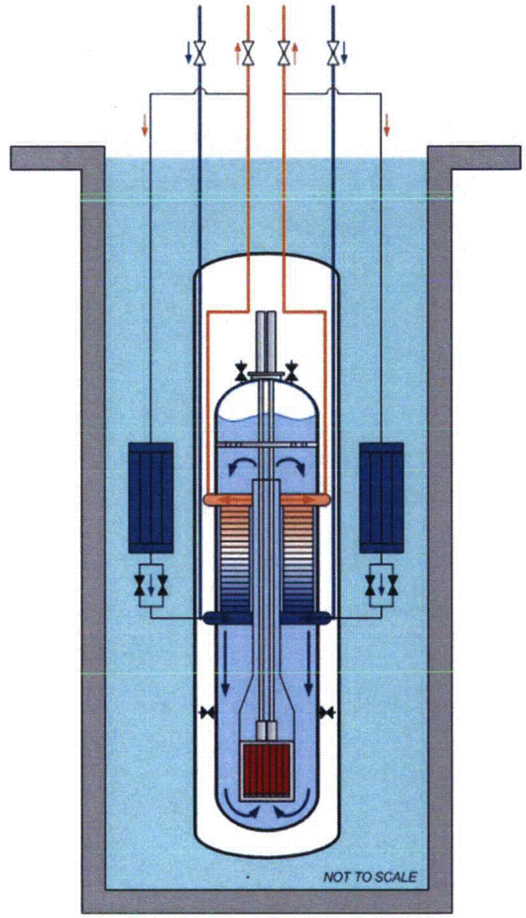
*** NC: Natural Circulation**

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

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



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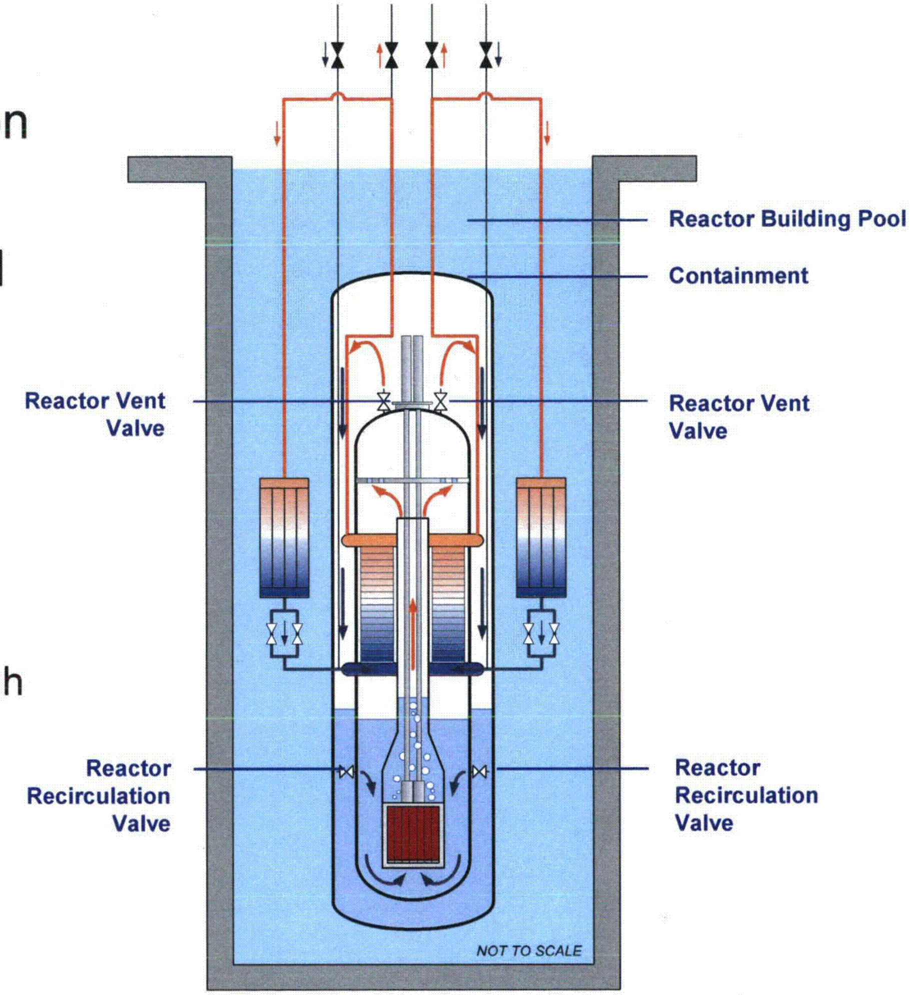
ECCS/Containment Heat Removal

- 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



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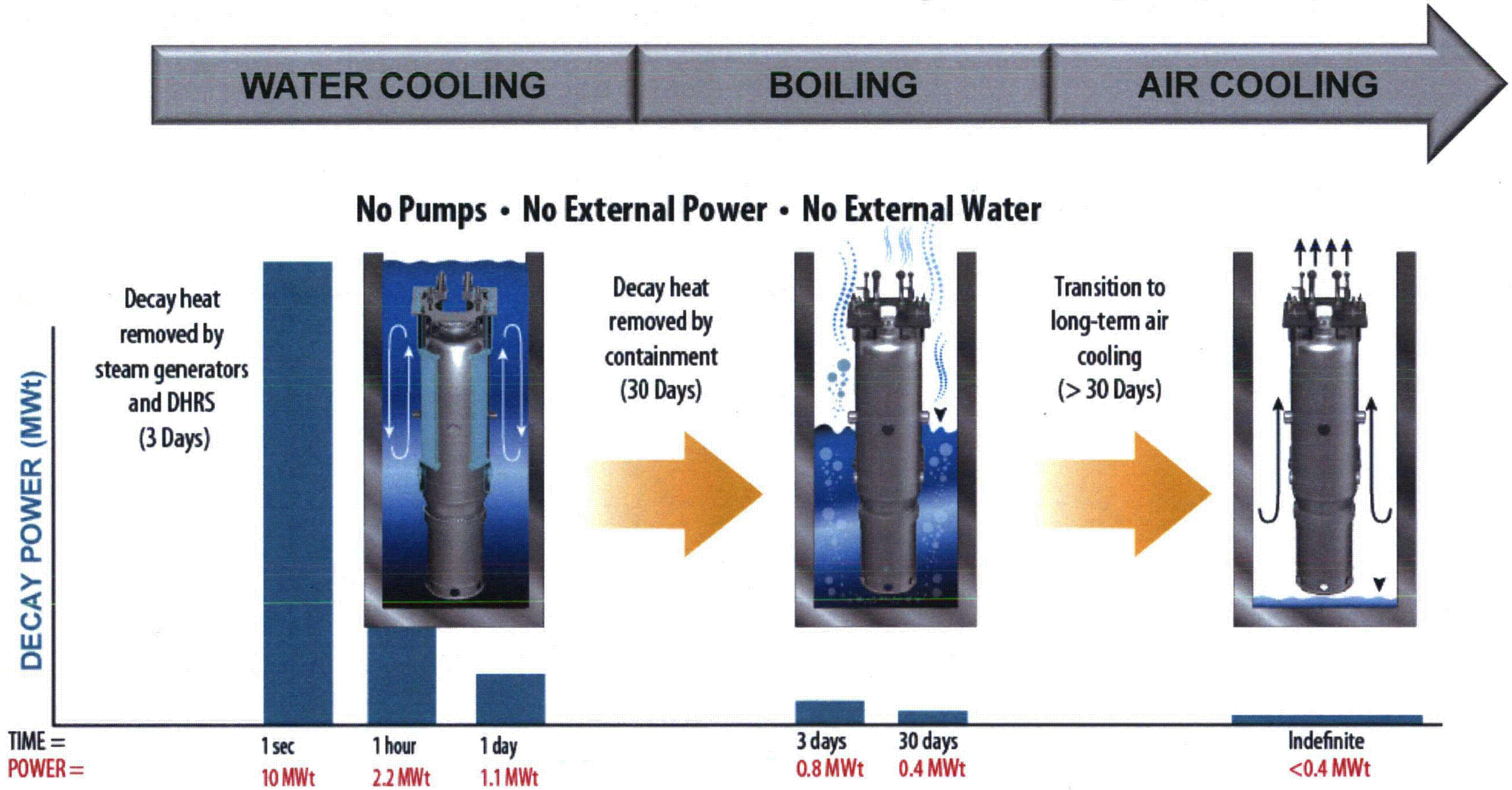
Stable Long-Term Cooling Under All Conditions

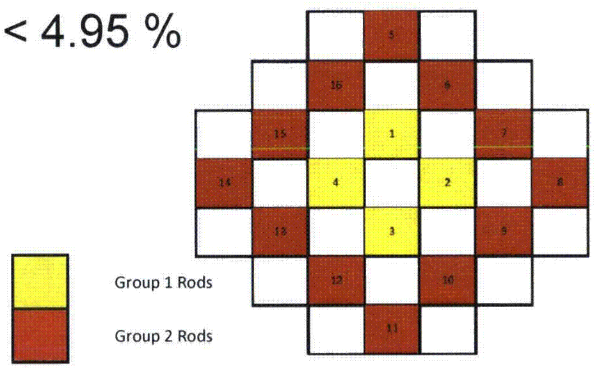
Reactor and nuclear fuel cooled indefinitely without pumps or power

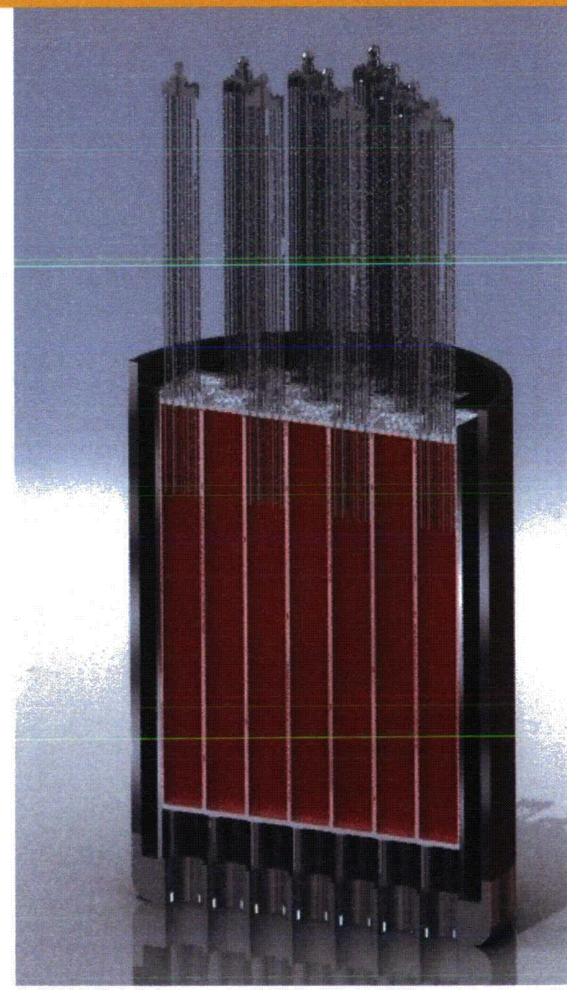


** Based on conservative calculations assuming all 12 modules in simultaneous upset conditions and reduced pool water inventory.*

NuScale Core Design

- 17x17 lattice
- Approximately half-height
- 37 assemblies / 16 control rod clusters
- UO2 fuel pellets
- Clad material – Zr-4 or advanced clad
- Negative reactivity coefficients
- 24 month cycle length at 95% capacity factor (695 effective full power day)
- U-235 enrichment < 4.95 %





Fuel Design Team

Fuel Design Team

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Roles and Responsibilities

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Quality Assurance

- NuScale has adopted ASME NQA-1 2008/2009 Addenda
- {{ }}3(a)
- {{ }}3(a)
- The audit identified four non-compliances
  - Design assumptions
  - Independently review and requirements traceability
  - Authentication of records
  - Definition of basic component not properly implemented
- {{ }}3(a)
  - All four to be completed Dec 31, 2012
- {{ }}3(a)

Software Quality Assurance

- {{ }}3(a)
- {{ }}3(a)
- {{ }}3(a)
- All future development work will be performed in accordance with ASME NQA-1 2008/2009

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Interactions

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Schedule Implications

Fuel Design Schedule

- Pre-submittal activities
  - Fuel mechanical design
  - Fuel mechanical testing
  - Fuel rod design
- Post-submittal activities
  - Confirmatory fuel mechanical testing
  - If required, fuel mechanical and rod design

Schedule Overview

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Schedule Overview

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Pre-Submittal Activities

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Post-Submittal Activities

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Key Milestones

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Opportunities for Testing Observations

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Summary

- Competent, experienced team functioning as planned
- Detailed schedule provides a path for success
- Making tangible progress

Questions?

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Contents

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I. Introduction

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II. Code Description

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II-2. Fuel rod design codes

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II-3. Summary of development

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II-8. Coolant/Cladding temperature

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II-9. Pellet-clad gap conductance

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II-10. Pellet temperature

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II-11. Fission gas release (1)

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II-11. Fission gas release (2)

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II-12. Mechanical models

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II-13. Clad creep

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II-14. Clad corrosion

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III. Application Analyses to NuScale SMR

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IV. Assessment of Design Methodology

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IV-1. Fuel rod design criteria

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- NUREG-0800, US NRC SRP 4.2, II. Acceptance Criteria (Mar. 2007, Rev. 03)
- Applicable Regulatory Guide

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Fuel system damage criteria	Fuel rod failure criteria
I. Stress/Strain, or loading limits	I. Hydriding
II. Strain fatigue	II. Cladding collapse
III. Fretting wear	III. Overheating of cladding
IV. Oxidation, hydriding, and crud	IV. Overheating of fuel pellets
V. Dimensional change	V. Excessive fuel enthalpy
VI. Internal pressure	VI. Pellet/cladding interaction
VII. Hydraulic loads	VII. Bursting
VIII. Control rod reactivity and insertability	VIII. Mechanical fracturing

IV-2. {{ }}3a fuel rod/system design criteria (1)

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IV-2. {{ }}3(a) fuel rod/system design criteria (2)

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IV-2. {{ [redacted] }}3(a) fuel rod/system design criteria (3)

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IV-3. Fuel rod design methodology

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V. Quality Assurance

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VI-1. Quality Assurance

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Design-Specific Review Standard

Objective

Achieve agreement on the appropriate set of Specified Acceptable Fuel Design Limits (SAFDLs) for the NuScale fuel for the Design Control Document (DCD) Design-Specific Review Standard (DSRS)

Benefits

- NuScale
  - Design focused on issues directly related to plant safety
  - Streamlined DCD development
  - Reduced cost
- NRC
  - Review focused on issues directly related to plant safety
  - Streamlined DCD review
  - Focused combined operating license review
  - More efficient use of staff resources
- Customers
  - Plant operation focused on issues directly related to plant safety

NuScale SAFDL Approach

Recommended strategy for development of the NuScale DSRS:

- **Group-1**: Analyses to be performed in support of Design Certification and Operating License Application
  - Analyses directly related to demonstrating plant safety

  Group-2: Analyses required by SRP not relevant
  - Demonstrate conditions underpinning acceptance criteria are precluded by inherent design features, e.g., LBLOCA
  - Operating regime limitations change acceptance criteria relevance to NuScale design

Group 1 Examples

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Group 2 Examples

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Group 2 Examples (continued)

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A. Fuel System Damage

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B. Fuel Rod Failure

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C. Fuel Coolability

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Feedback and Next Steps

- Staff feedback
  - Design team

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  - Schedule
- Continue to develop detailed justification
  - E-room
- DSRS and plans for next interaction with the staff