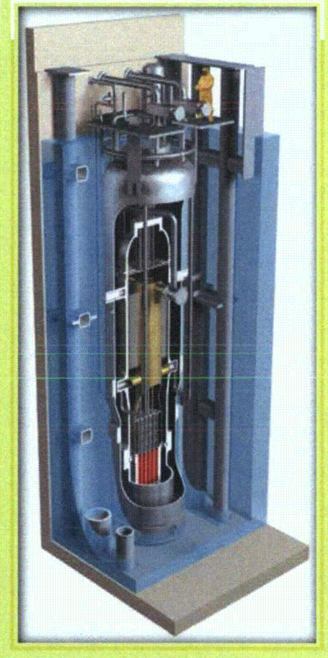
Reactor Coolant System, Connected Systems, and Emergency Core Cooling System



November 20, 2013

NuScale Nonproprietary

NUSCALE POWER™

NP-PM-0913-4811-NP

Agenda

- Purpose
- Plant overview
- Background
- Design information for select Chapter 5, emergency core cooling system (ECCS) components, and decay heat removal
- NuScale DSRS Chapters 5 and 6 – information for NRC development of NuScale DSRS
- Results achieved and next steps

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Purpose

- Provide information for NRC development of NuScale DSRS for Chapter 5 and ECCS
  - design information
  - SRP/DSRS information
- Identify need for future DSRS Chapters 5 and 6 engagements

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Overview and Background

Steve Mirsky, P.E.

Washington DC Licensing Manager

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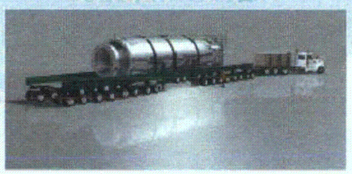
Plant Design Overview

Factory Manufacturing

Module includes Containment and Reactor Vessel

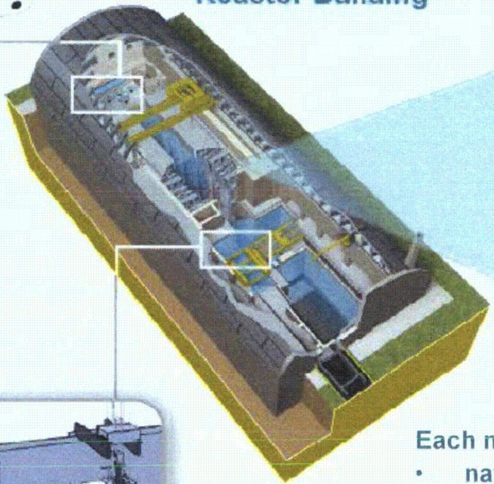
Shipped by Truck, Rail, or Barge

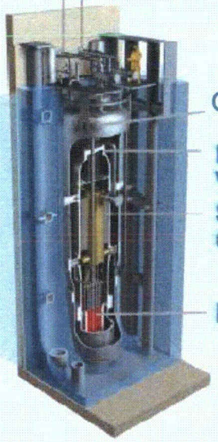


Skid-Mounted Steam Turbine/Generator

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

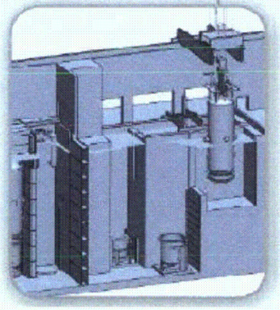
12 Module Reactor Building





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

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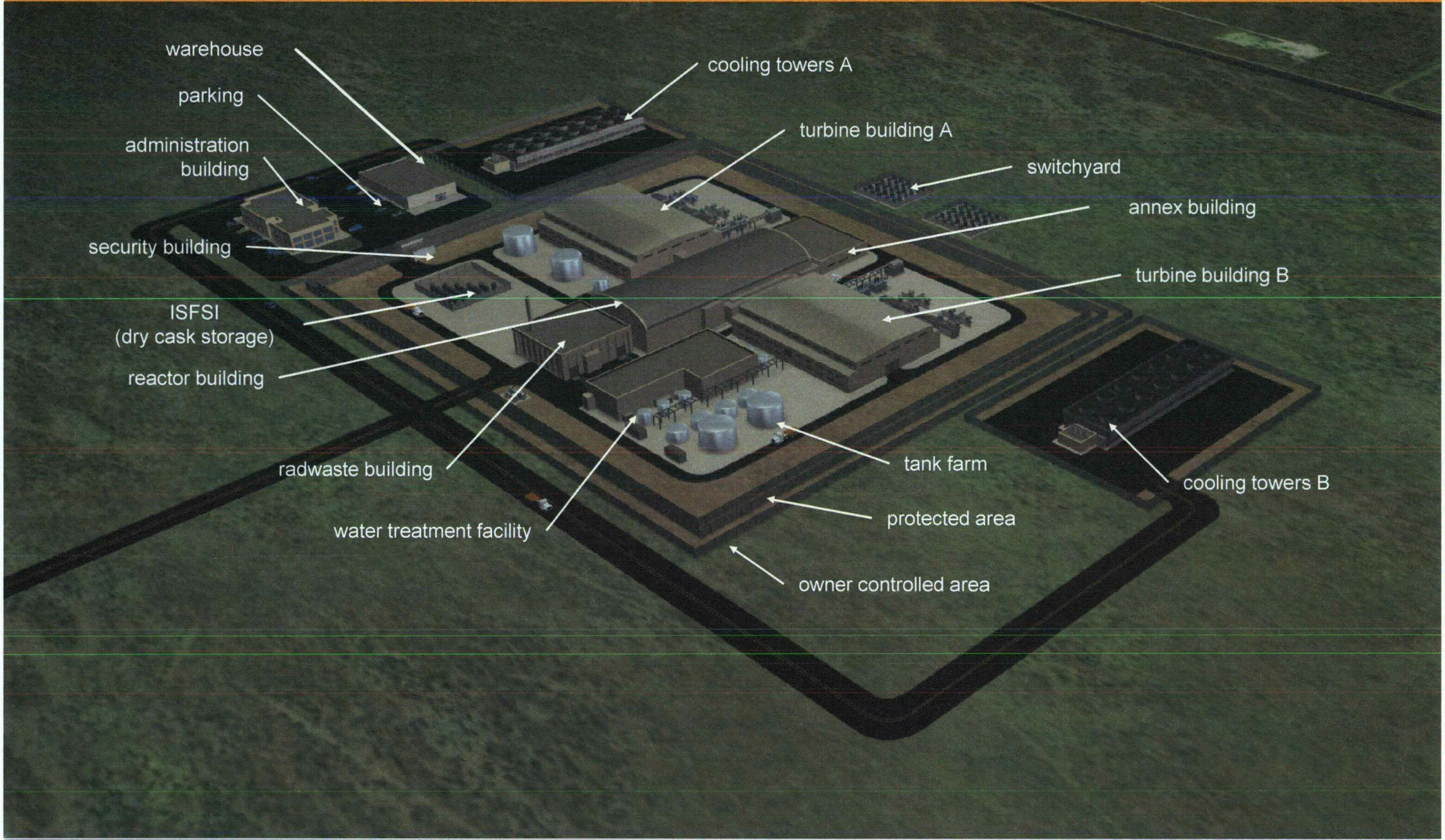
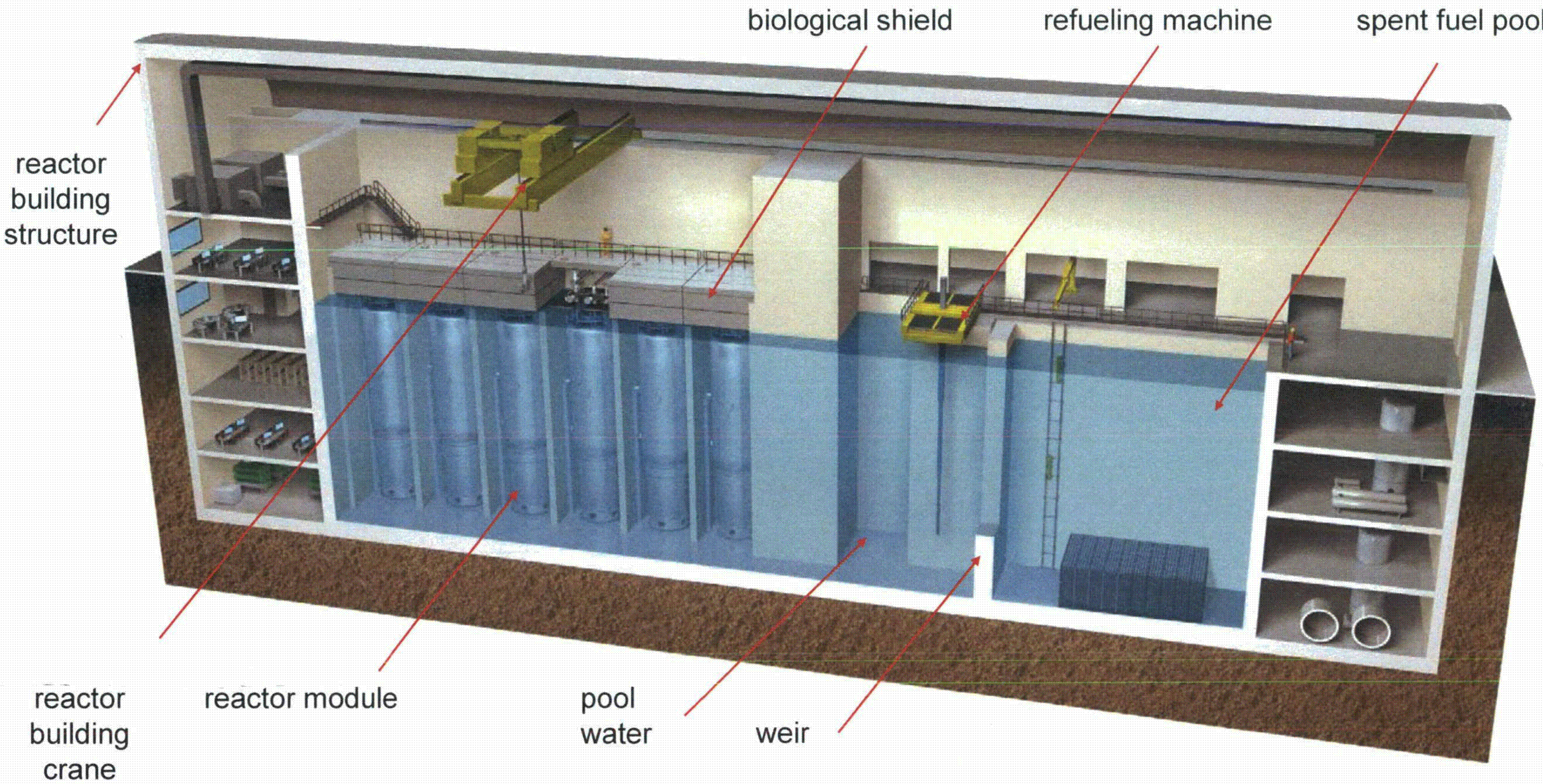
Site Aerial View



Reactor Building Cross-Section

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



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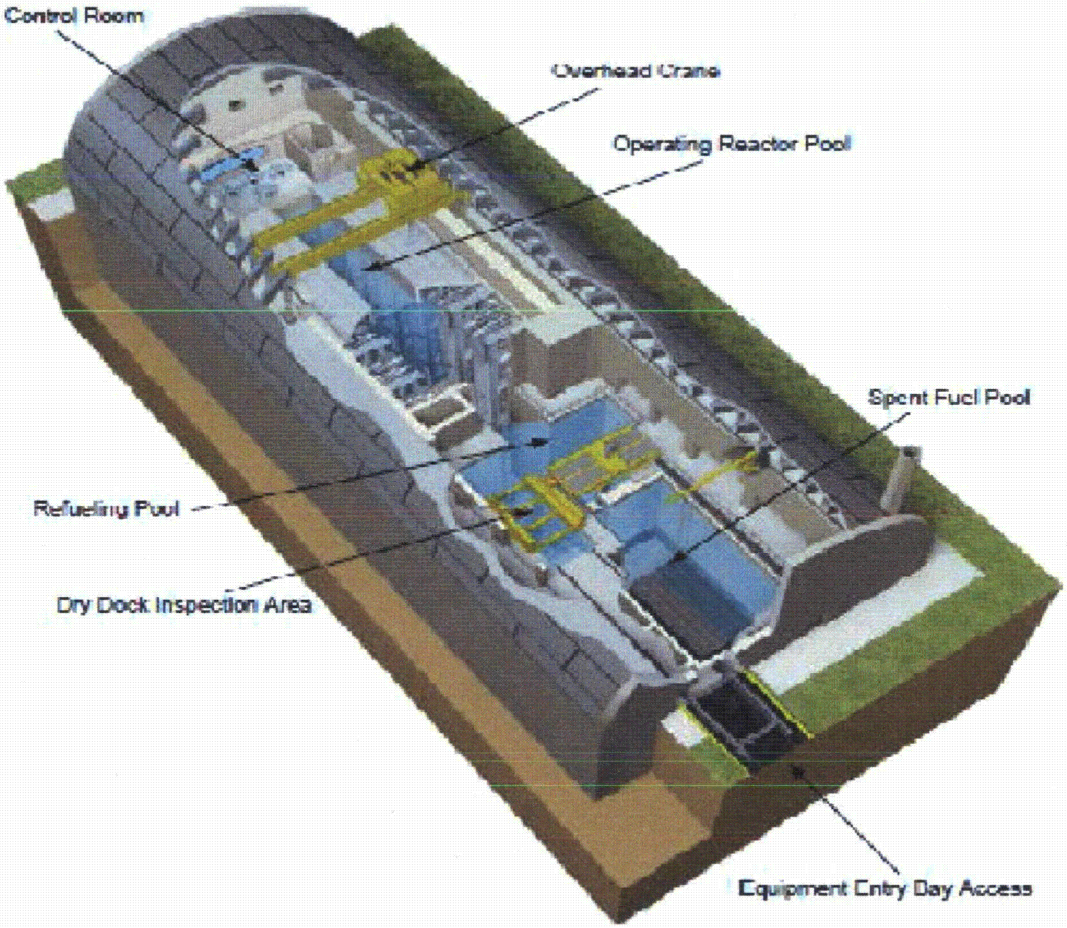
Reactor Building Overhead View



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

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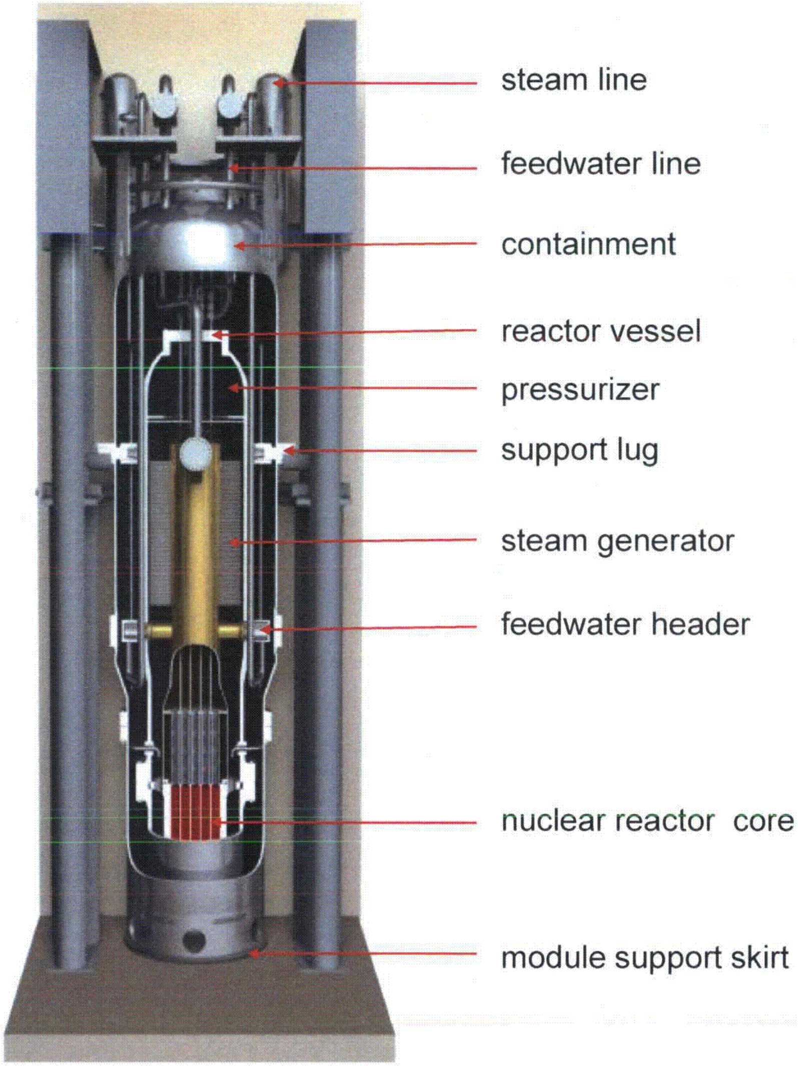
Reactor Module Overview

Natural convection for cooling

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

Simple and small

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



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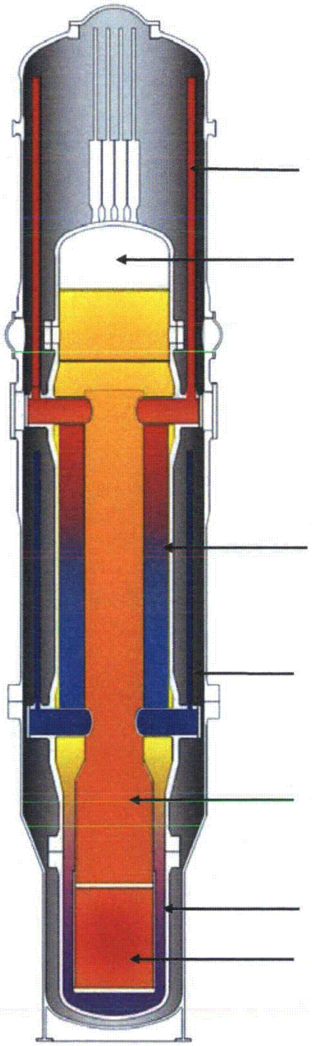
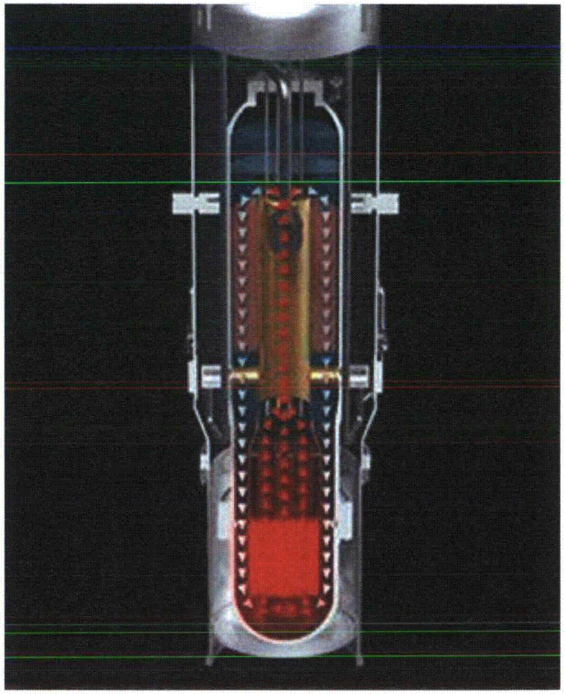
Module Normal Operation

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





primary coolant flow path

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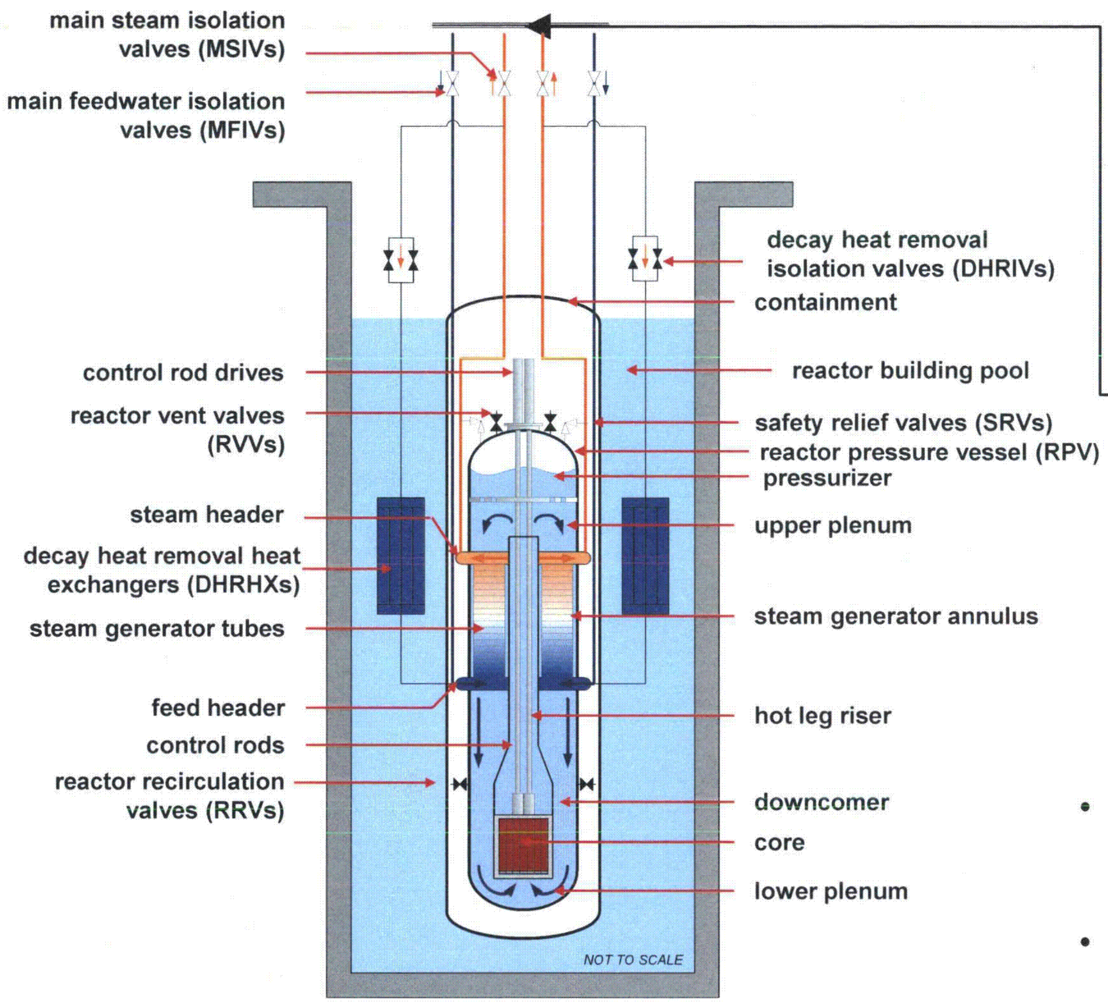
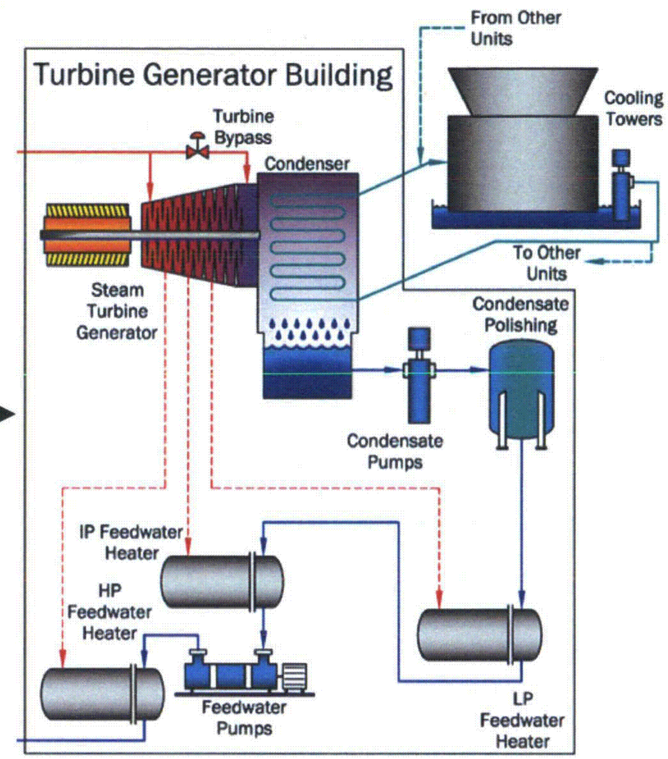
NuScale Power Train





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

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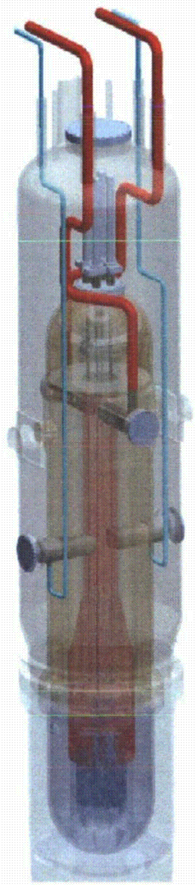
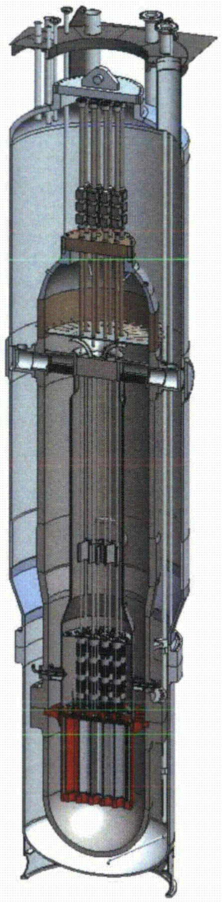
Containment Design

High Pressure Containment – Enhanced Safety

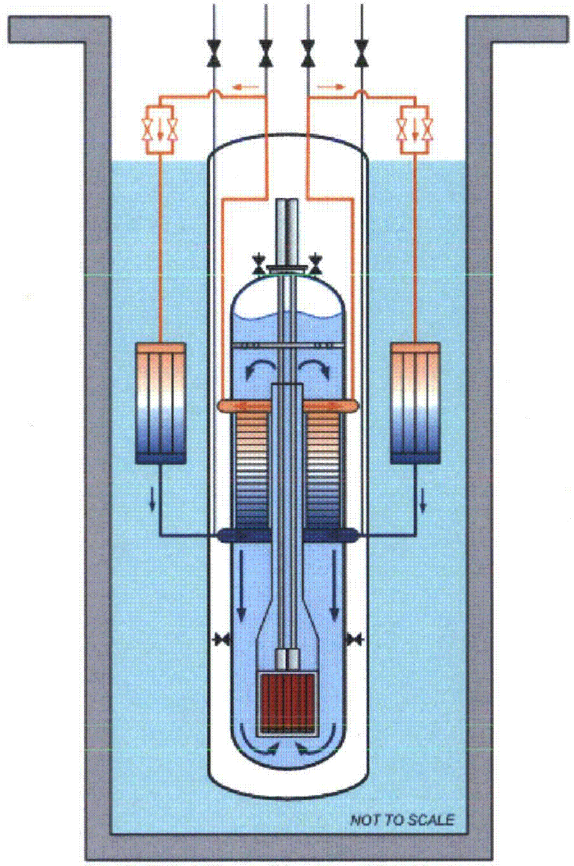
- Containment volume sized so that core does not uncover following a LOCA (prevents fuel heat-up)
- Large water pool keeps containment shell cool and promotes efficient post-LOCA steam condensation
- Insulating vacuum
  - significantly reduces conduction and convection heat transfer during normal operation
  - 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





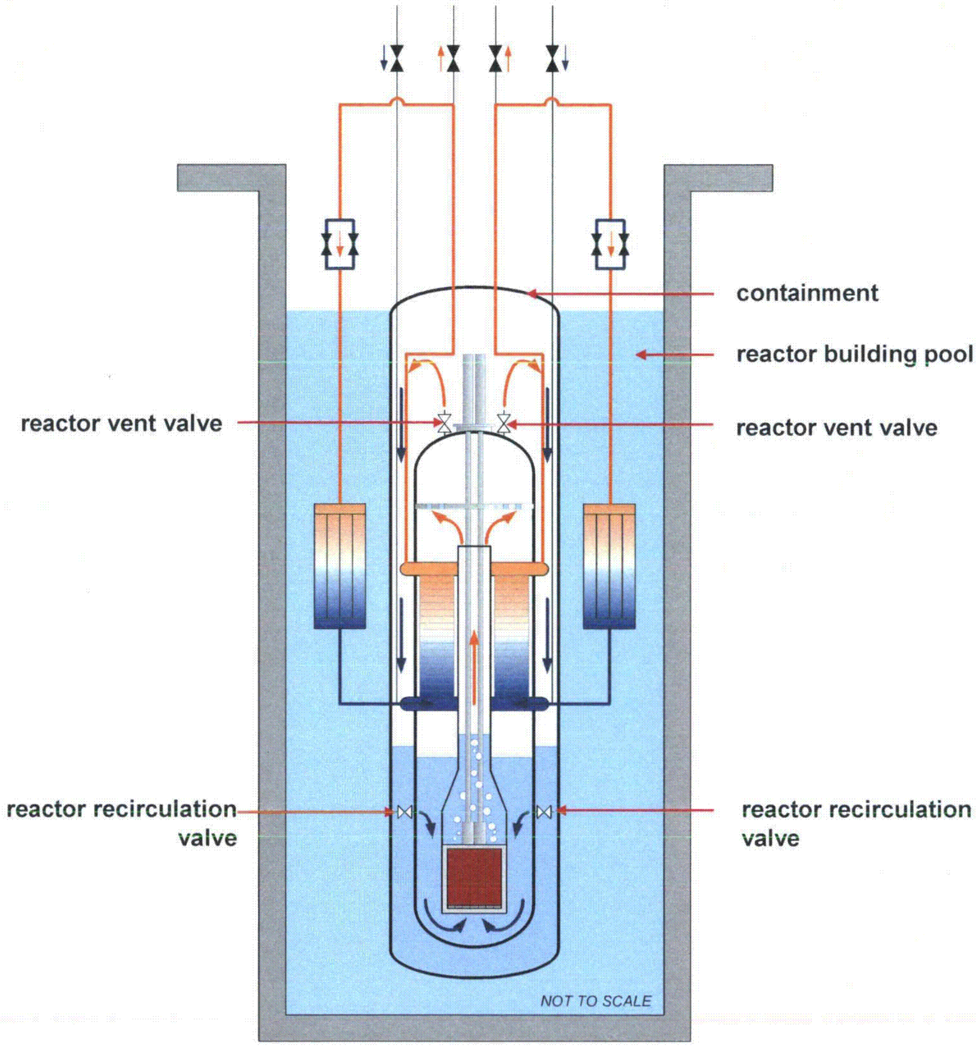
Passive Decay Heat Removal System

- 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
- 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)



Emergency Core Cooling System (ECCS) and Containment Heat Removal System (CHRS)

- 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



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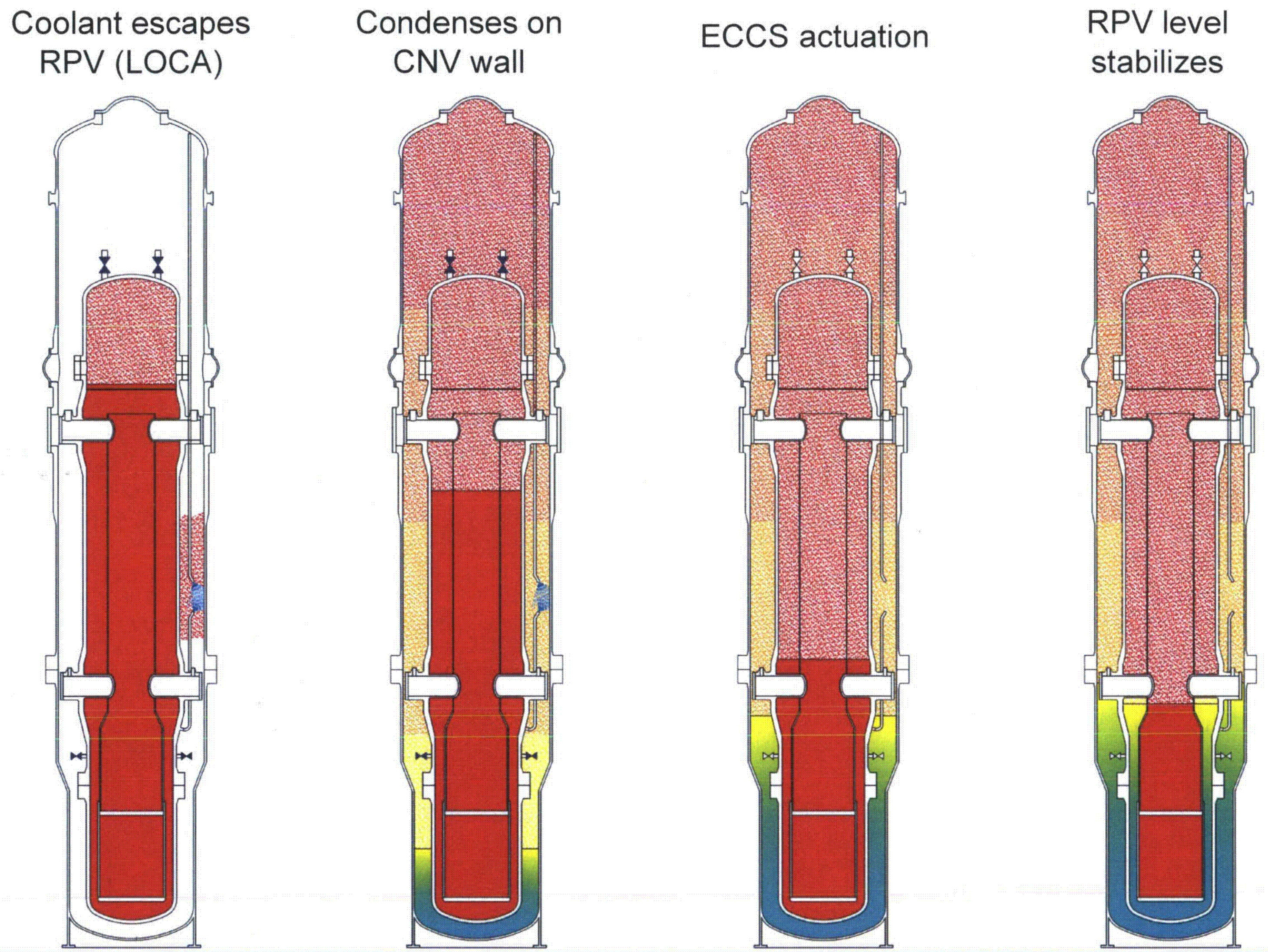
ECCS Accident Operation



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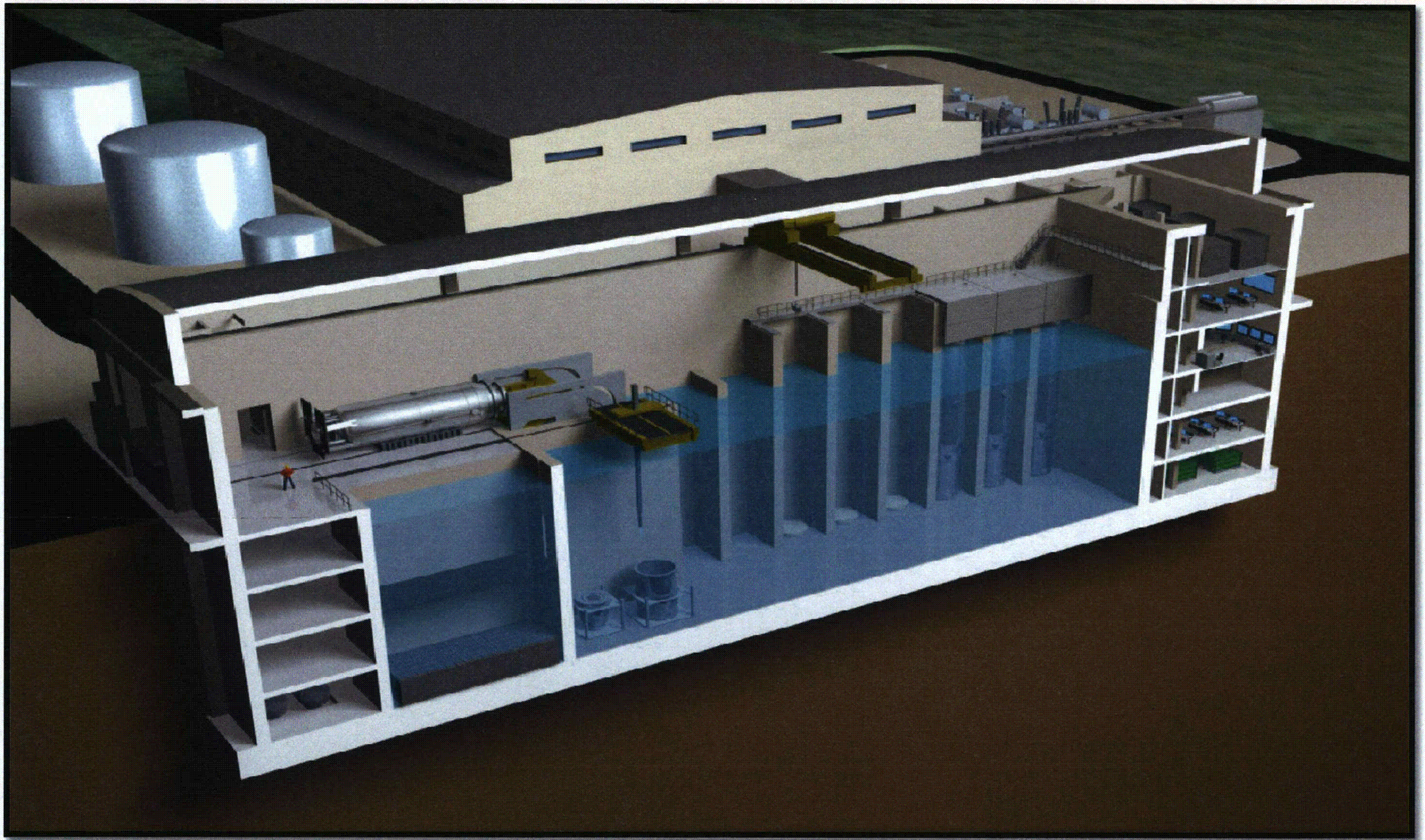
Module Component Assembly



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Design Simplification

- **New system**
  - containment evacuation
- **Eliminated systems**
  - containment spray
  - containment fan cooler
  - auxiliary feedwater
  - ECCS injection and recirculation
  - steam generator blowdown
  - main plant electrical generator hydrogen supply
- **Eliminated components**
  - reactor coolant pumps
  - ECCS pumps, tanks, and 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

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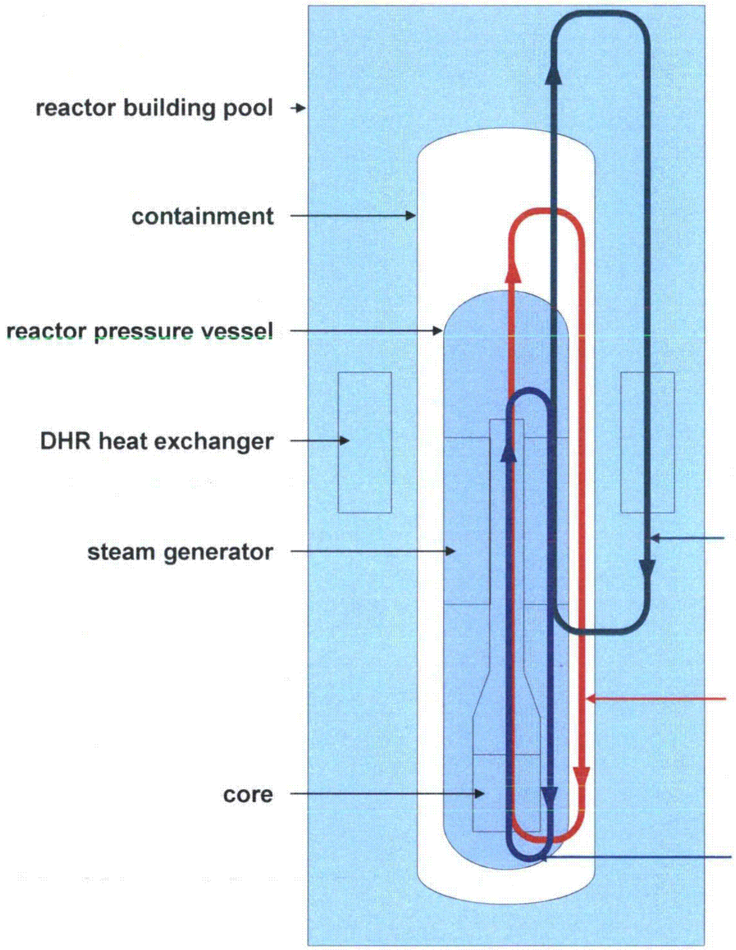
Passive Cooling Systems



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

DHRS BC* transient operation

ECCS BC* accident operation

RCS NC* normal operation

- BC: boiling and condensation
- NC: natural circulation

Background

- July 2012 submittal: Gap Analysis Summary Report
- May 2013 Federal Register Notice (FRN): mPower DSRS issued for public comment
- June 2013 meetings: NuScale Design-Specific Review Standard development
  - Chapter 6 (Containment Design)
  - Chapters 11 and 12 (by telephone)
- August 2013 meetings: Design and SRP/DSRS information for NRC development of NuScale DSRS Chapters 7, 9, and 10

Design of Select Chapters 5 and 6 Systems and Components

- Chapter 5
  - reactor module
  - reactor coolant system (RCS)
    - RCS vs. reactor coolant pressure boundary (RCPB)
    - pressurizer and pressure control
  - reactor vessel
  - reactor vessel internals
  - steam generators
  - design provisions permitting access for inspections
- Chapter 6
  - emergency core cooling system
- Decay heat removal (DHR) system

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Reactor Module

Dr. Tamás Liszkai, P.E.

Reactor Module Design Supervisor

Reactor Module Design Status

- Design status

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Reactor Module Components

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Reactor Module Critical Dimensions

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Reactor Module Metal Mass

{{

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Reactor Module Service Conditions

Service Condition	Parameter	CNV	RPV	SG
Design Conditions	Internal pressure	{{		
	External design pressure			
	Design temperature			}}3(a)-(c)
Normal operating conditions	Internal pressure	{{ }}3(a)-(c)	1850 psia	{{ }}3(a)-(c)
	External pressure	{{		
	Temperature			}}3(a)-(c)

Reactor Module Operation

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

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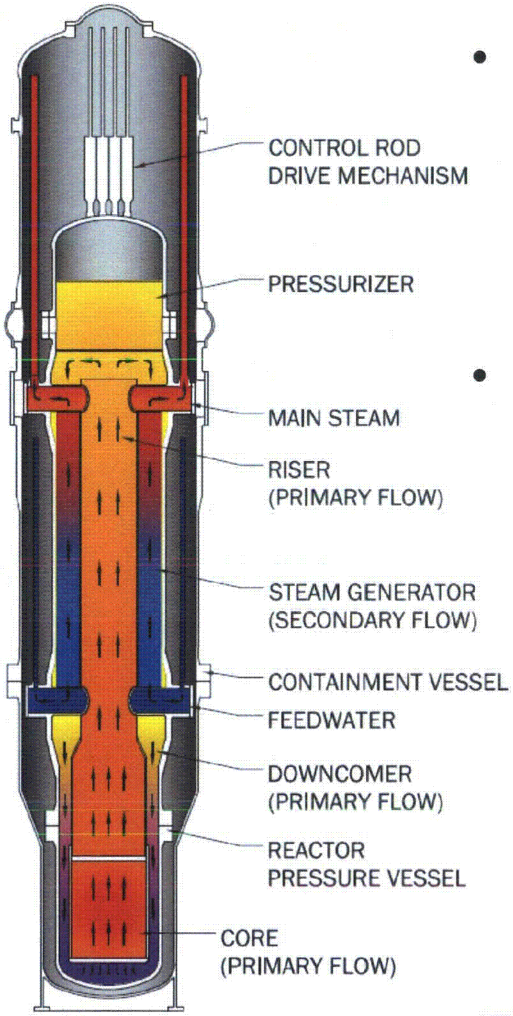
  - small, dry, high pressure capable



- Safety heat removal
  - ECC primary side
  - natural circulation inside CNV to RPV
- DHR secondary side
  - natural circulation within feedwater (FW) and main steam (MS) lines thru DHR

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Reactor Coolant System

J.J. Arthur, P.E.

Mechanical Engineering Supervisor

Reactor Coolant System

- Design status

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Reactor Coolant System

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Reactor Coolant System

RCS versus RCPB {{

The NuScale RCS consists of

- reactor pressure vessel (RPV), including the reactor vessel nozzles to which connecting RCPB systems and components are attached
- pressurizer at the top (upper head region) of the RPV interior, including the baffle plate, heaters, and spray nozzles
- RPV code safety valves
- steam generator tube bundles and plenums within the RPV
- components internal to the reactor vessel that partition and direct the reactor coolant flow within the vessel (e.g., riser, downcomer, and lower plenum)

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Reactor Coolant System

RCS versus RCPB

{{

The RCPB consists of the pressure-retaining portions of the following:

- RCS (as defined on preceding slide)
- systems and components connected to the RCS
  - control rod drive mechanisms
  - ECC system valves
  - chemical and volume control (CVC) system piping up to and including the outermost containment isolation valve

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Reactor Coolant System

- System functions
  - The reactor coolant
    - transfers the heat generated in the reactor core to the power conversion systems during normal operation and forced cooldown.
    - transfers decay heat to the reactor pool. Neither power nor additional water inventory is required to provide long term core cooling.
    - provides neutron reflection and moderation in the reactor core.
  - The RPV provides a high integrity pressure boundary to contain the reactor coolant, support and enclose the reactor core, and provide a secondary barrier against the release of radioactive fission products.
  - The reactor vessel internals and the RPV direct the natural circulation primary coolant flow.

Reactor Coolant System

- System functions
  - The pressurizer maintains pressure and level within the normal operating range, dampens pressure responses to transient operating conditions, and provides a surge volume to accommodate density changes in the primary coolant.
  - The SGs provide superheated steam to the turbine generator system. The tubes and plenums serve as a reactor coolant pressure boundary and prevent the transfer of radioactivity generated in the core to the secondary system.

•Documents available for audit

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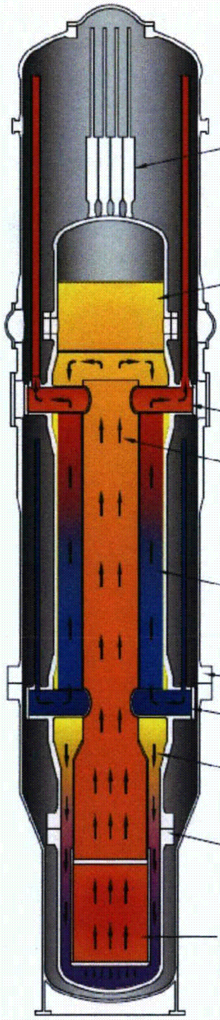
Reactor Coolant System



The RCS consists of a primary coolant heat transfer circuit between the reactor core and the two helical-coil SGs.

- **Integral design:** the reactor core, SGs, pressurizer, and the primary coolant flow path are entirely contained within the RPV, which serves as part of the reactor coolant pressure boundary.
  - eliminates large piping within the primary system, thus eliminating the potential for a high-consequence accident resulting from a large pipe break and subsequent rapid loss of coolant
- **Natural circulation:** the difference in density and height between the core and SGs drives the reactor coolant flow.
  - passive natural circulation eliminates transients associated with reactor coolant pump malfunction and simplifies RCS maintenance
  - contains more than four times the volume of currently certified PWRs per unit of power, improving accident and transient performance

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Reactor Coolant System

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- **Steam generation:** two once-through, helical coil SGs are located in the annular space between the riser and RPV.
  - secondary flow is inside the steam generator tubes

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Pressurizer

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Design	Nominal pressurizer steam volume (ft^3)	Rated thermal power (MW_{th})	Ratio of steam volume to power (ft^3/MW_{th})
SIR	2830	1000	2.83
NuScale	{{ }}3(a)-(c)	**160**	{{ }}3(a)-(c)
IRIS	1730	1000	1.73
AP1000	1100	3415	0.32
US-APWR	840	4451	0.19
US-EPR	883	4590	0.19

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Reactor Pressure Vessel

Dr. Tamás Liszkai, P.E.

Reactor Module Design Supervisor

Reactor Module, Containment Vessel, Reactor Pressure Vessel Assembly

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Reactor Pressure Vessel Support System Inside the Containment Vessel

{{

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Reactor Pressure Vessel Design and Normal Operating Data

Service Condition	Parameter	Value	
Design Conditions	internal design pressure	{{	
	external design pressure		
	design temperature		}}3(a)-(c)
Normal Operating Conditions	internal RPV pressure	1850 psia	
	external RPV pressure	{{	
	RPV temperature		
	feedwater pressure		
	feedwater temperature		
	steam pressure		
	steam temperature		}}3(a)-(c)

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Reactor Pressure Vessel Weld Locations

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Reactor Pressure Vessel Wall Material Selection

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Reactor Pressure Vessel Wall Material Selection

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Steam Generator Feedwater Plenums

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Steam Generator Steam Plenums

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Reactor Pressure Vessel Surface Cladding

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Reactor Pressure Vessel Closure Flanges

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Control Rod Drive Mechanism (CRDM) Nozzle Assembly

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Reactor Pressure Vessel 54 Effective Full-Power Year (EFPY) Fluence

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54 EFPY RPV 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

P-T Curve for EOL Core Critical

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P-T Curve for Inservice EOL Leak Test

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Preliminary RPV Surveillance Program

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Pressurizer

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Reactor Safety Valves

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Reactor Vessel Internals

Dr. Tamás Liszkai, P.E.

Reactor Module Design Supervisor

Reactor Vessel Internals Functional Requirements

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Reactor Vessel Internals Assembly

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Reactor Vessel Internals General Support Functions

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Steam Generators

Dr. Tamás Liszkai, P.E.

Reactor Module Design Supervisor

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Integrated Helical Coil Steam Generator

- Two SGs are fully integrated within the RPV
- Contained in annulus between the upper riser and the RPV shell

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Two Independent Steam Generators

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Major Steam Generator Physical Dimensions

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Operating Conditions

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Steam Generator Materials

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Thermally Treated Alloy 690 Tubing

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Tube Supports

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Flow Induced Vibration

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Inspection Considerations

Dr. Tamás Liszkai, P.E.
Reactor Module Design Supervisor

Provide Refueling Access

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Access for Repair, Maintenance, and Inservice Inspections

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Steam Plenum Access

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Access to Feedwater Plenums

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Pressurizer Heater Port Access

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Emergency Core Cooling System

J.J. Arthur, P.E.

Mechanical Engineering Supervisor

Emergency Core Cooling System

- Design status

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Emergency Core Cooling System

- System functions
  - provides a portion of the reactor coolant pressure boundary
  - transfers decay heat from the RCS to containment
  - re-circulates inventory retained in containment to keep core covered
- System design
  - system consists of four valves mounted directly to the reactor pressure vessel.
- Documents available for audit

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Emergency Core Cooling System

- The ECCS is used to ensure core cooling after a LOCA inside containment
- Returns coolant from the containment vessel (CNV) to the reactor pressure vessel and ensures core cooling
- The ECCS does not add inventory to the reactor coolant system, and a minimum inventory is required for its effective operation

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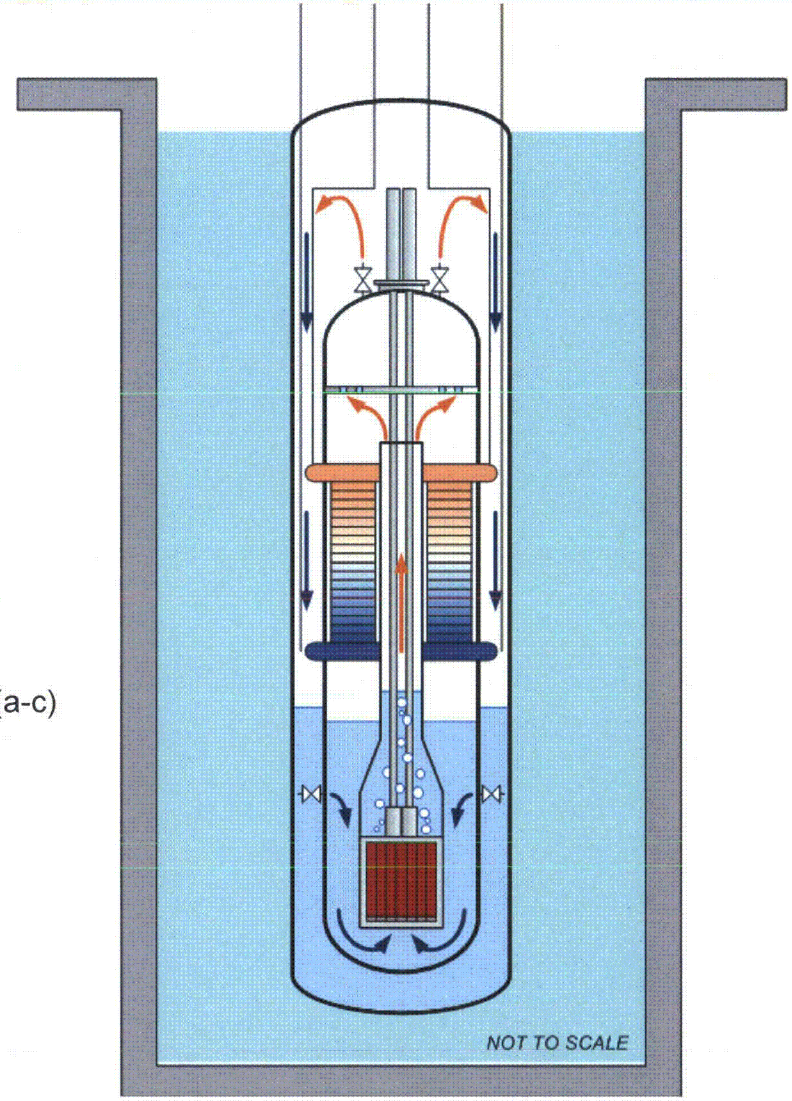
- Two reactor vent valves and two reactor recirculation valves provided, only one of each is required



Emergency Core Cooling System

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Emergency Core Cooling System

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Emergency Core Cooling System

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Emergency Core Cooling System

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Decay Heat Removal System

J.J. Arthur, P.E.
Mechanical Engineering Supervisor

Decay Heat Removal System

- Design status

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Decay Heat Removal System

- System function
  - provides secondary-side cooling for non-LOCA design-basis events when normal secondary-side cooling is unavailable*

{{ • System design

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Documents available for audit

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Decay Heat Removal System

- Design overview

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Decay Heat Removal System

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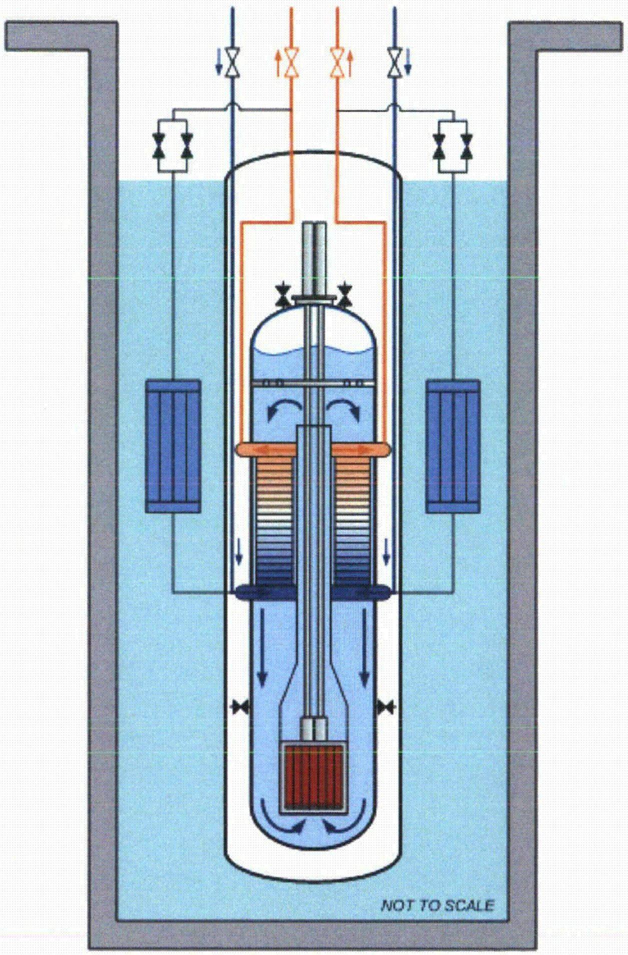

Decay Heat Removal System

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Design Specific Review Standard

Michael Brasel

Director, Licensing

NuScale Design Specific Review Standard

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NuScale Design Specific Review Standard

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NuScale Chapter 5 DSRS

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NuScale Chapter 5 DSRS

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NuScale Power™

NuScale Chapter 6 DSRS

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NuScale Chapter 6 DSRS

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NuScale Chapter 6 DSRS

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NuScale Design Specific Review Standard

SRP/DSRS INFORMATION

- Current NuScale assessment for each section is as indicated in overview tables on previous slides
- 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

Results Achieved and Path Forward

- Provided information for development of NuScale DSRS for select Chapters 5 and 6 sections
  - design information
  - SRP/DSRS information
- Plan for future interactions

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