Containment Isolation

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Nonproprietary

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Agenda

- Purpose
- Plant overview
- NuScale containment isolation valve (CIV) design approach
  - design issues driving NuScale's current CIV approach
  - technical justification for CIV design
  - decay heat removal (DHR) system design approach and justification
- Regulatory approach
  - applicable regulations
  - regulatory compliance and deviation
- Design Specific Review Standard (DSRS)
  - specific NuScale DSRS needs
- Results achieved and path forward
  - NRC feedback on information needed or concerns

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Purpose

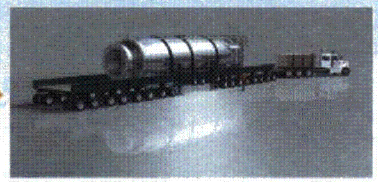
- Describe NuScale design approach to containment isolation
- Obtain NRC feedback on information needed to review NuScale containment isolation design
- Describe NuScale regulatory approach to containment isolation
- Discuss NuScale Design Specific Review Standard (DSRS) development

Plant Design Overview

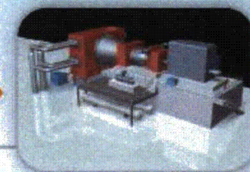
Factory Manufacturing

Module includes Containment and Reactor Vessel

Shipped by Truck, Rail, or Barge

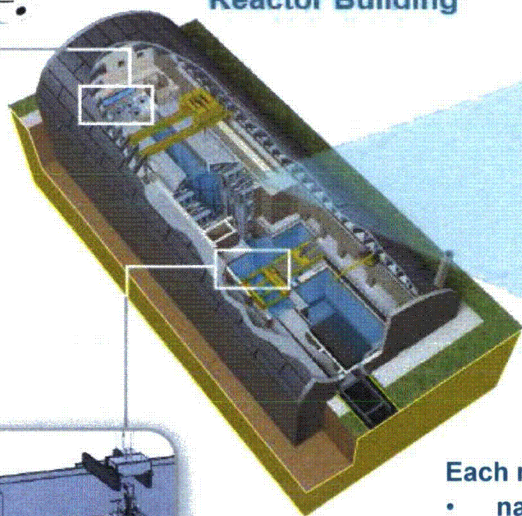


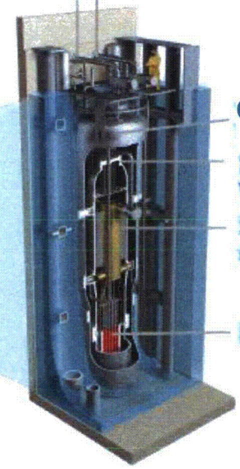
Skid-Mounted Steam Turbine/Generator



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

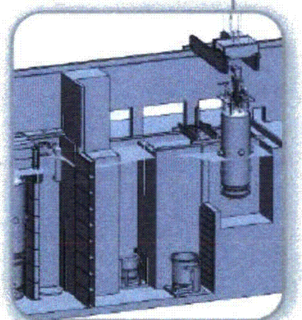
12 Module Reactor Building





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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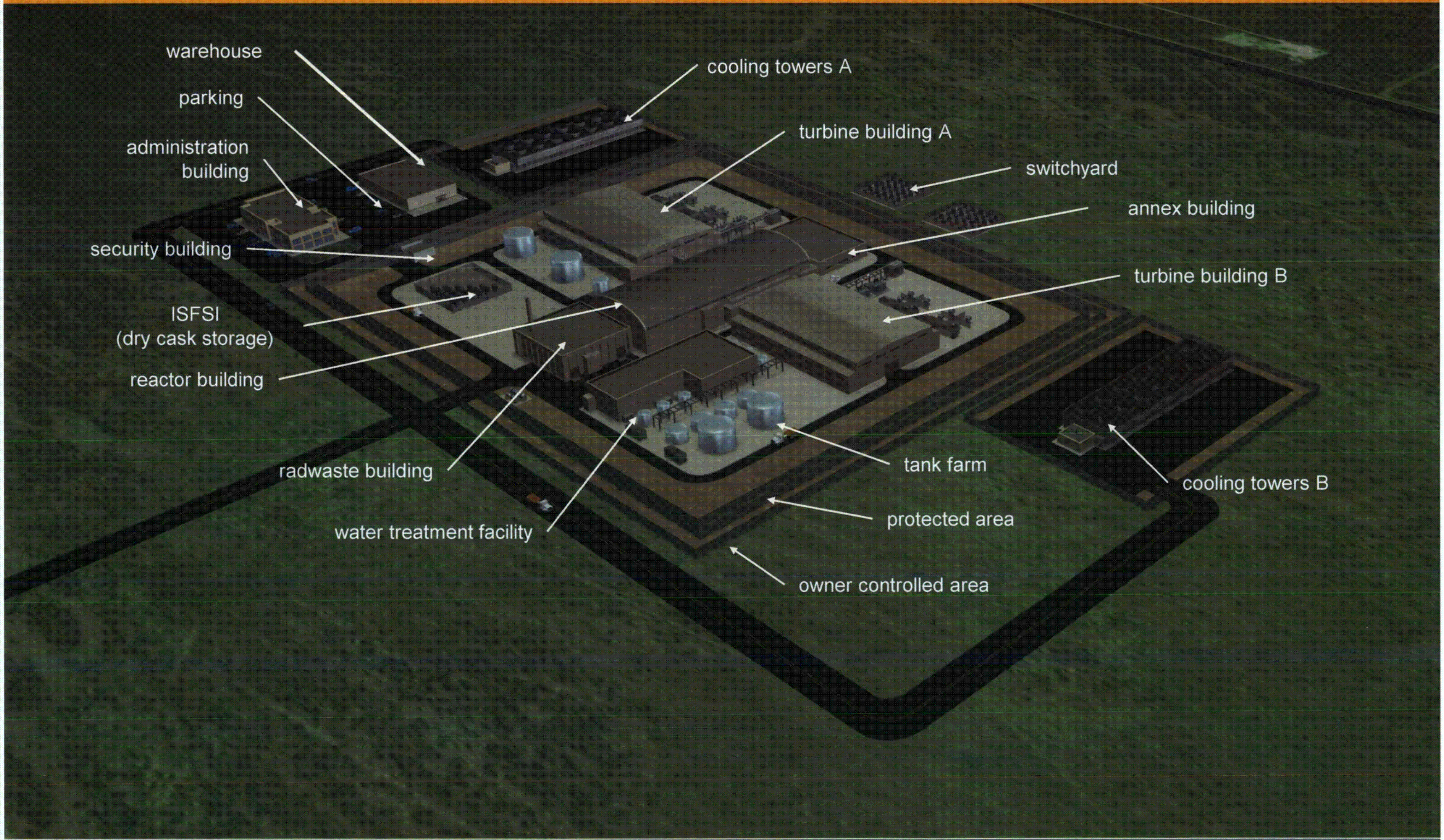
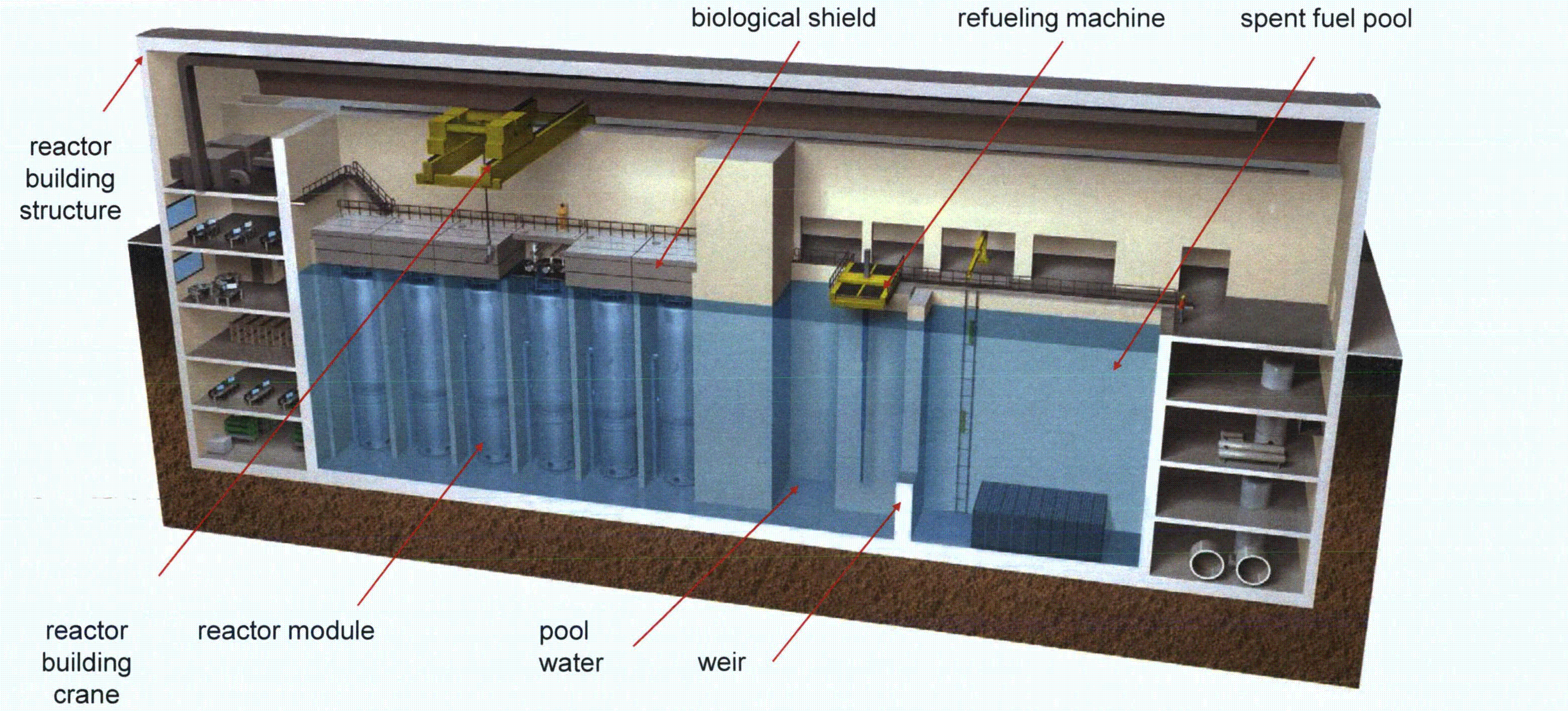
Site Aerial View



Reactor Building Cross-Section

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



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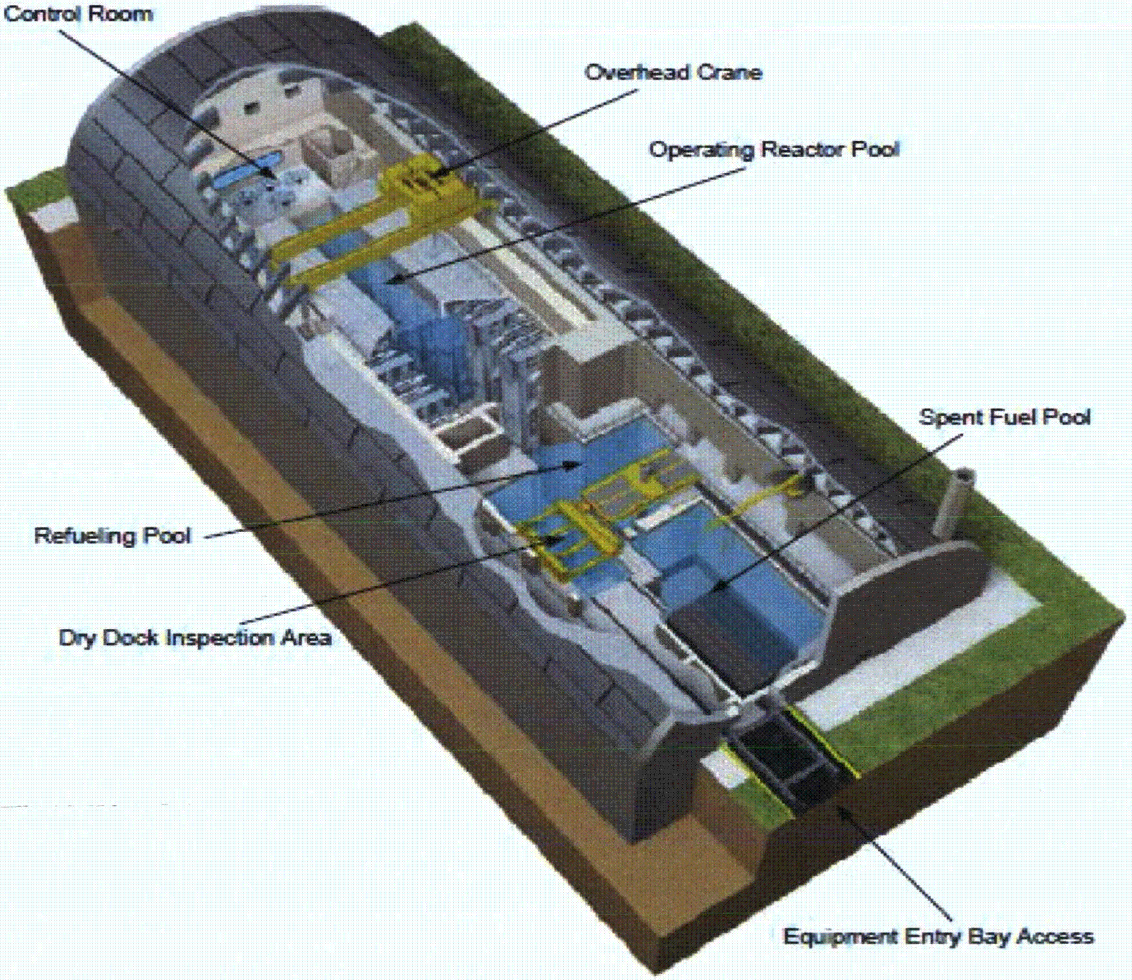
Reactor Building Overhead View



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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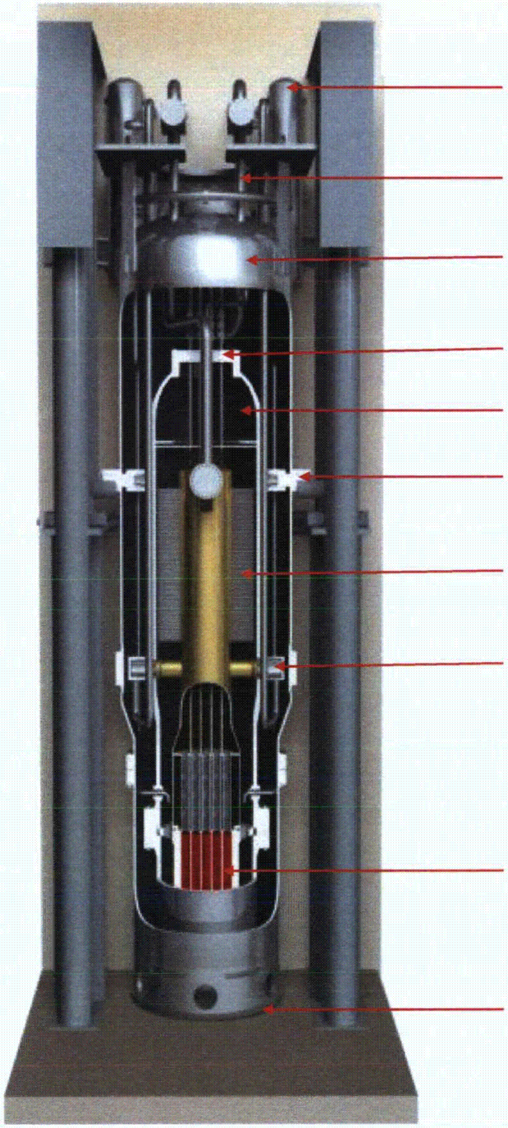
Reactor Module Overview

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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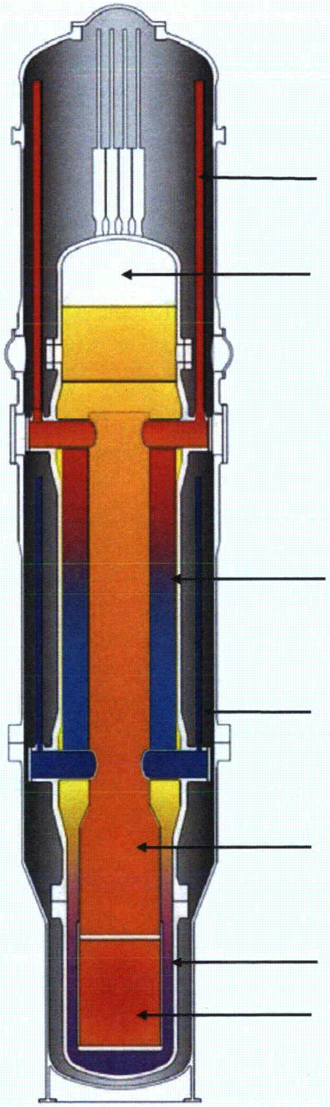
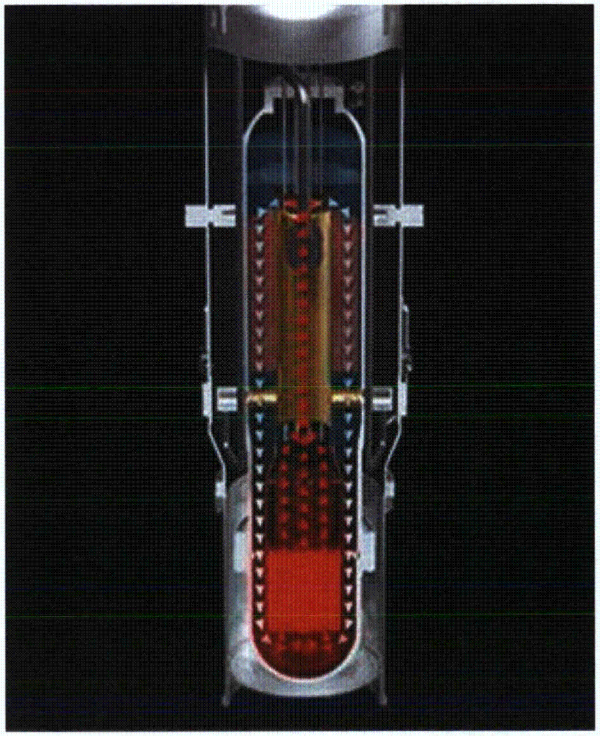
Module Normal Operation

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





primary coolant flow path

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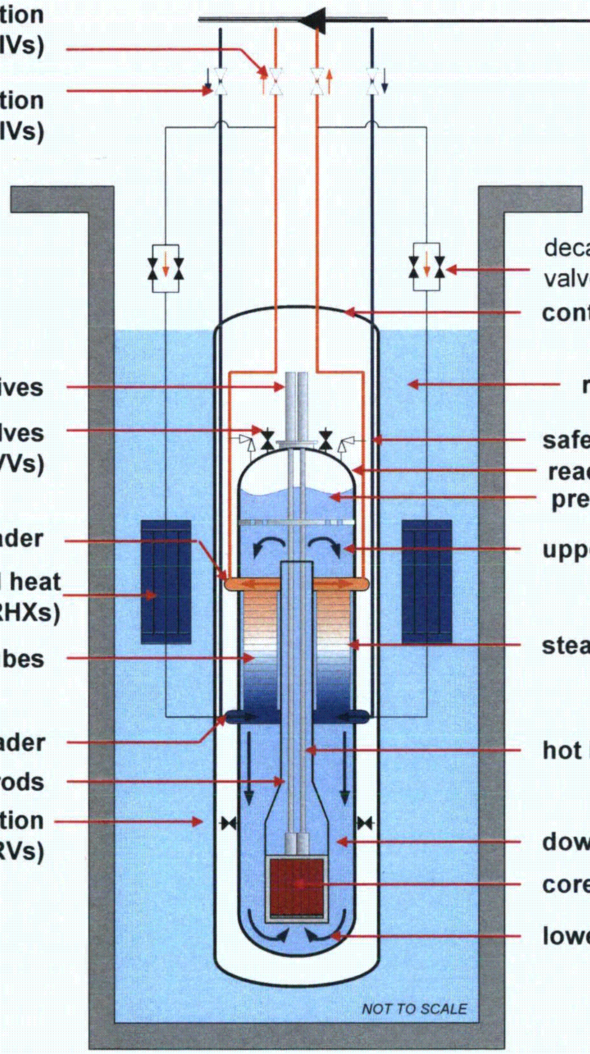
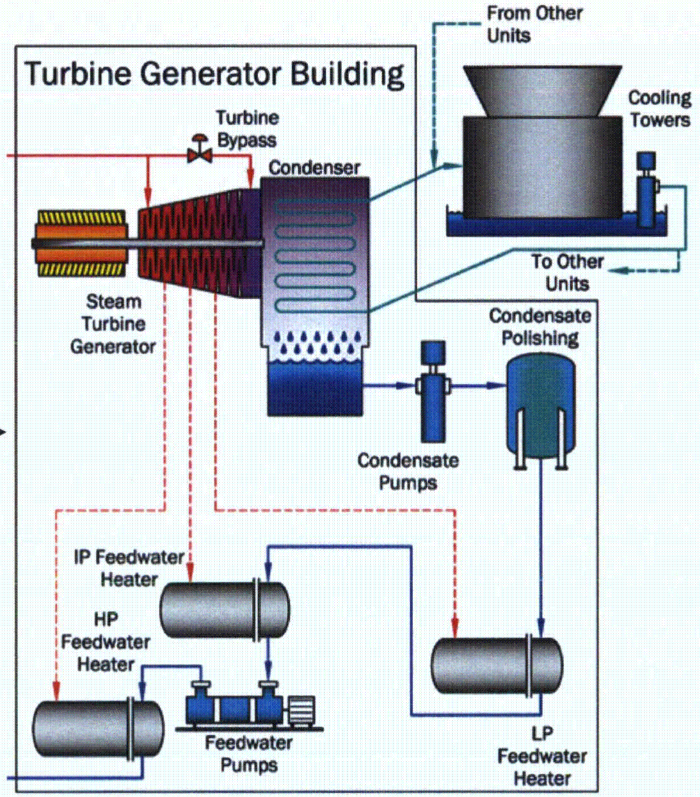
NuScale Power Train





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

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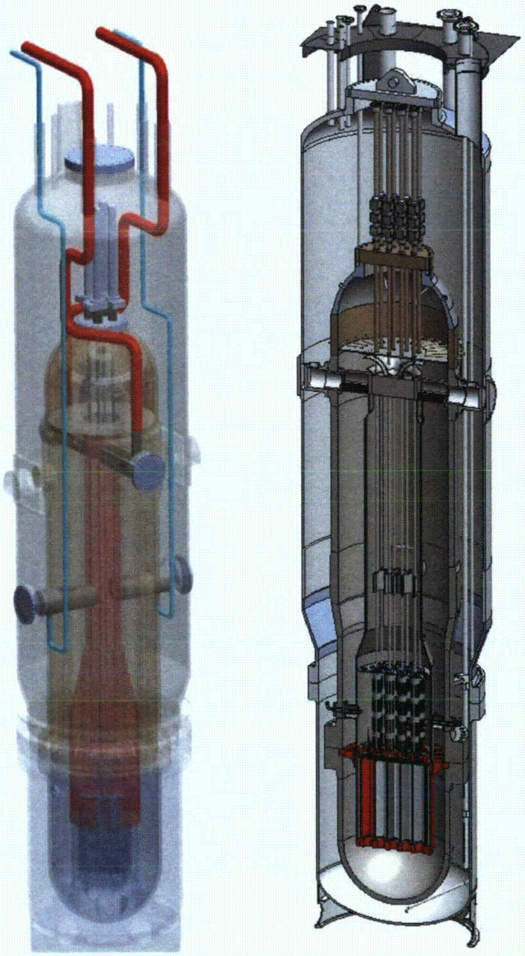
Containment Design

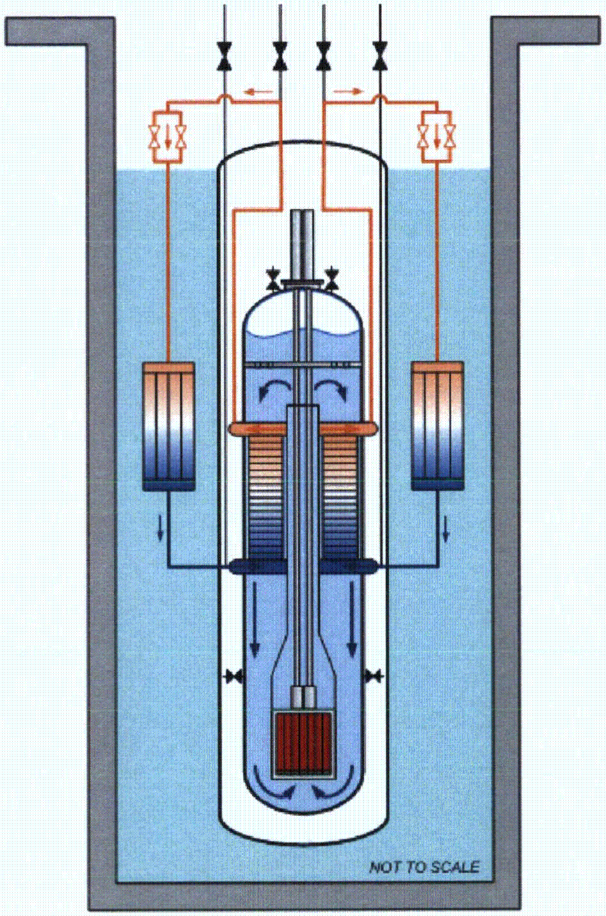
High Pressure Containment – Enhanced Safety

- 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) 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)



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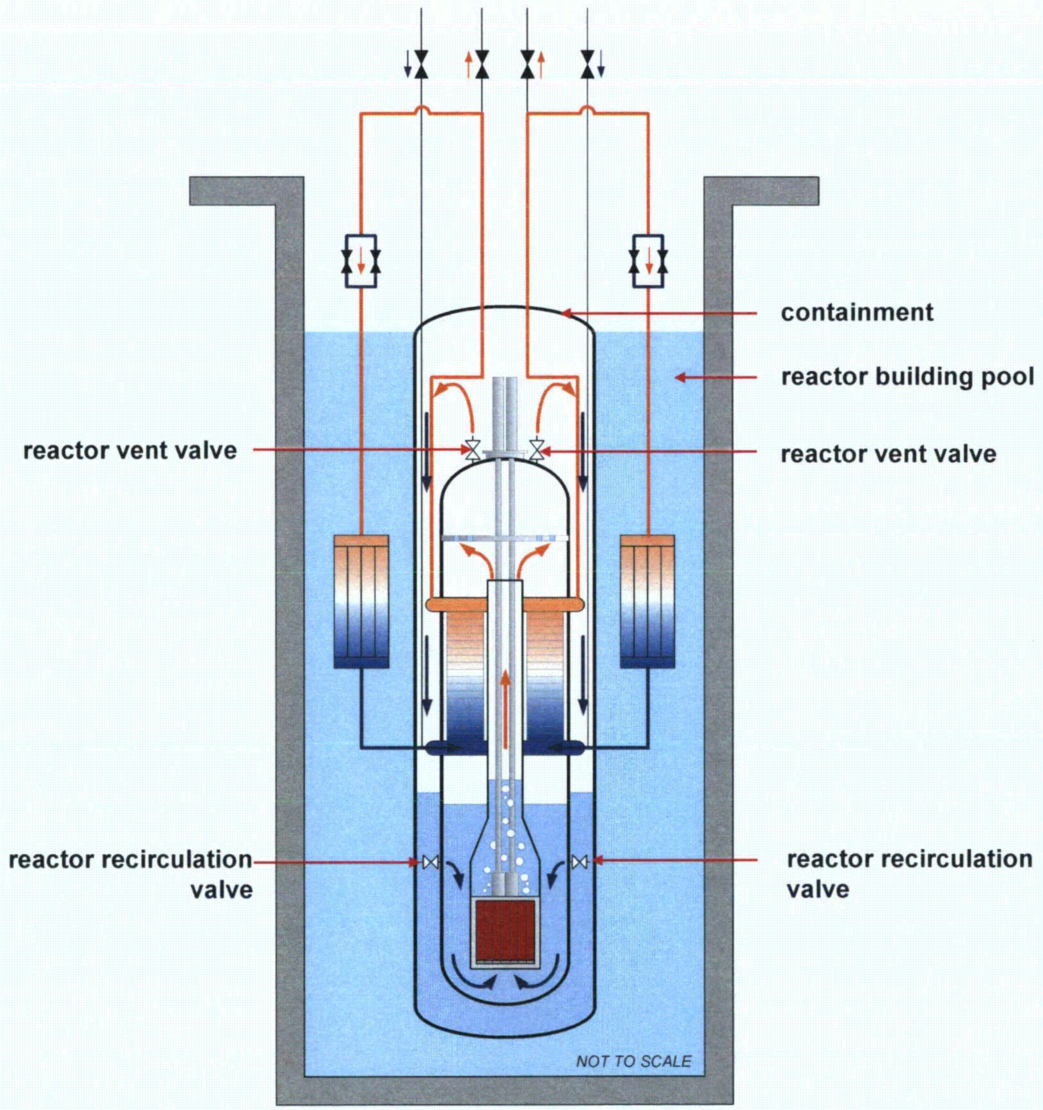
Emergency Core Cooling System (ECCS) and Containment Heat Removal System (CHRS)

- 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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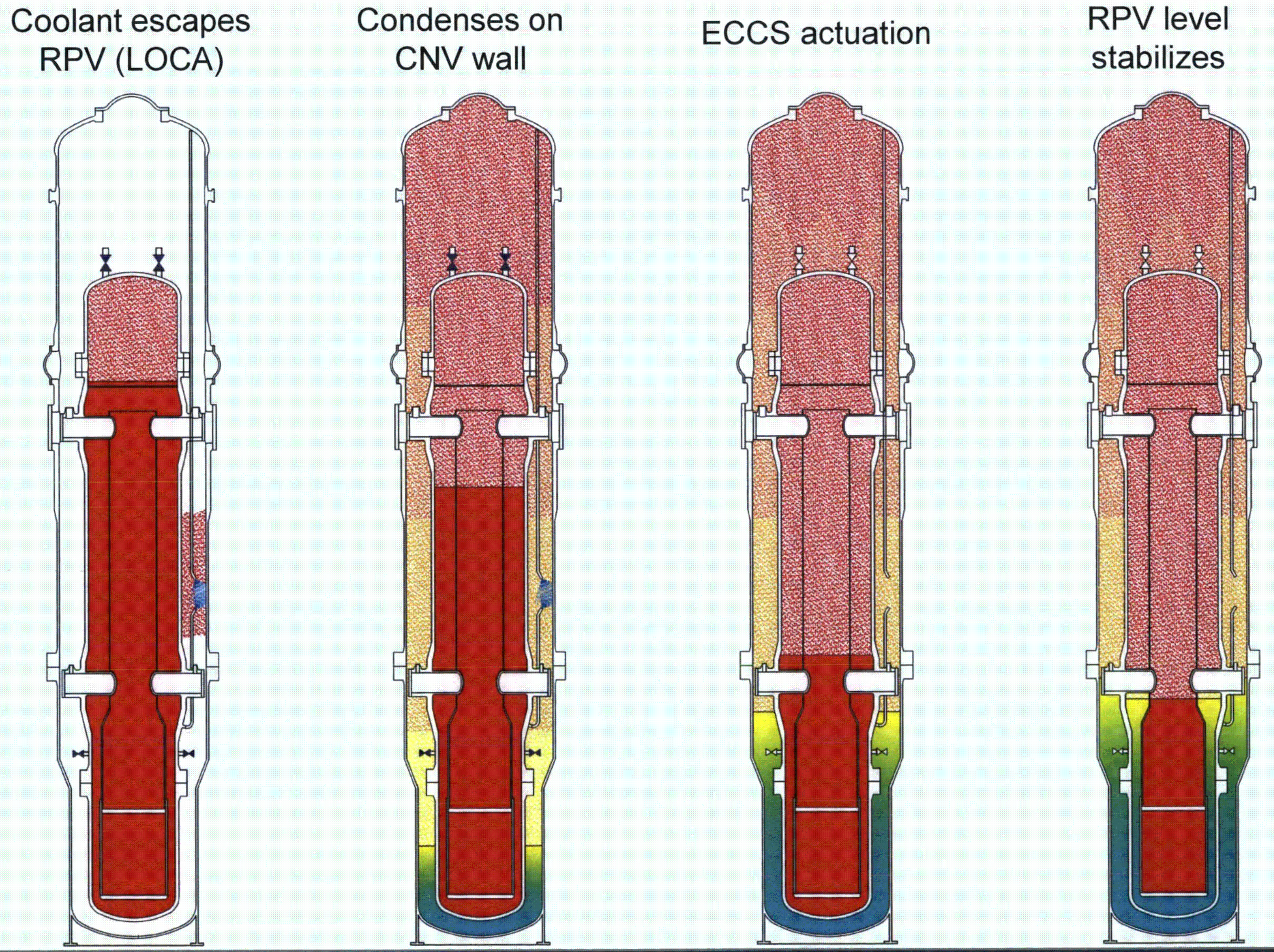
ECCS Accident Operation



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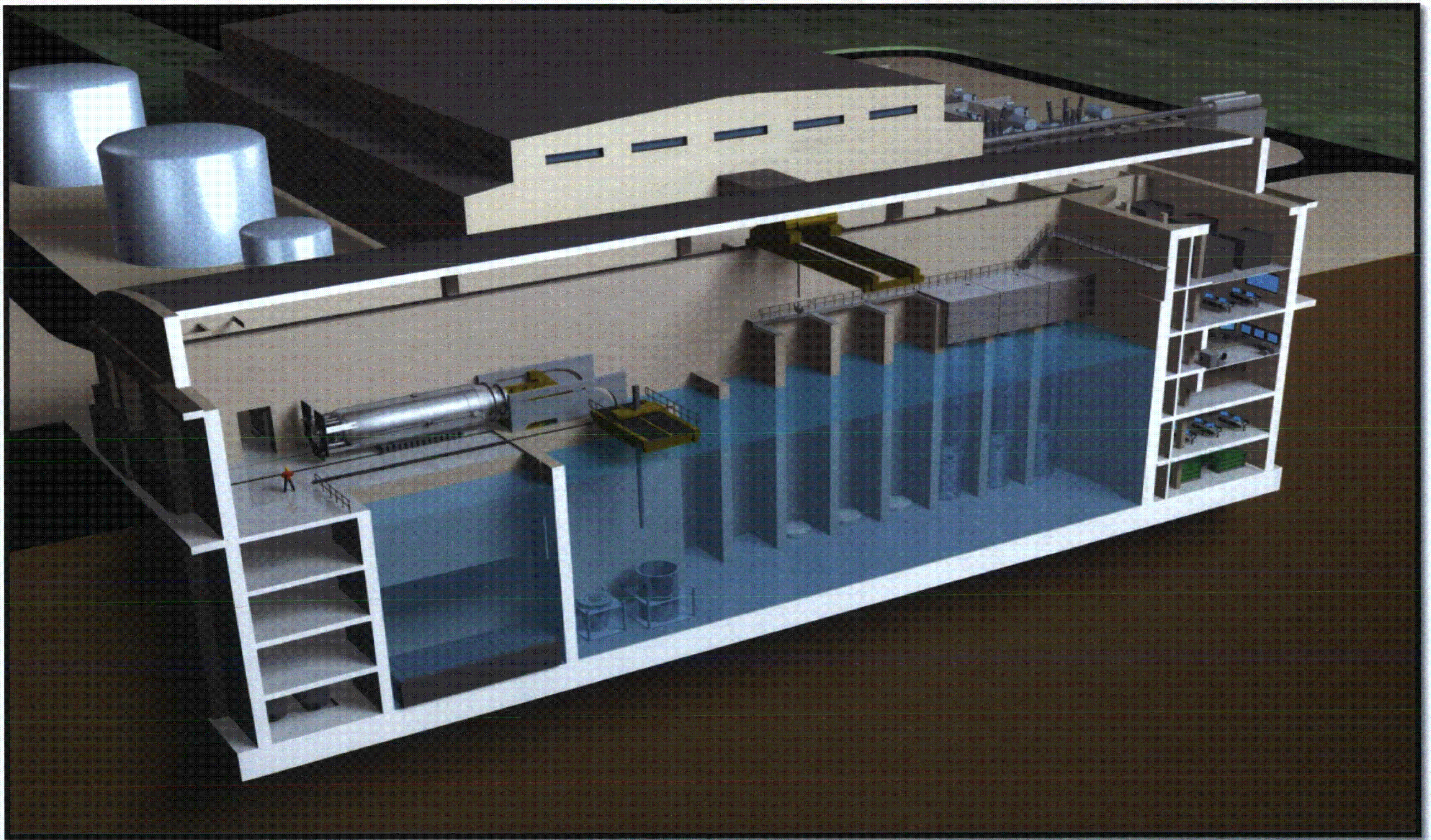
Module Component Assembly



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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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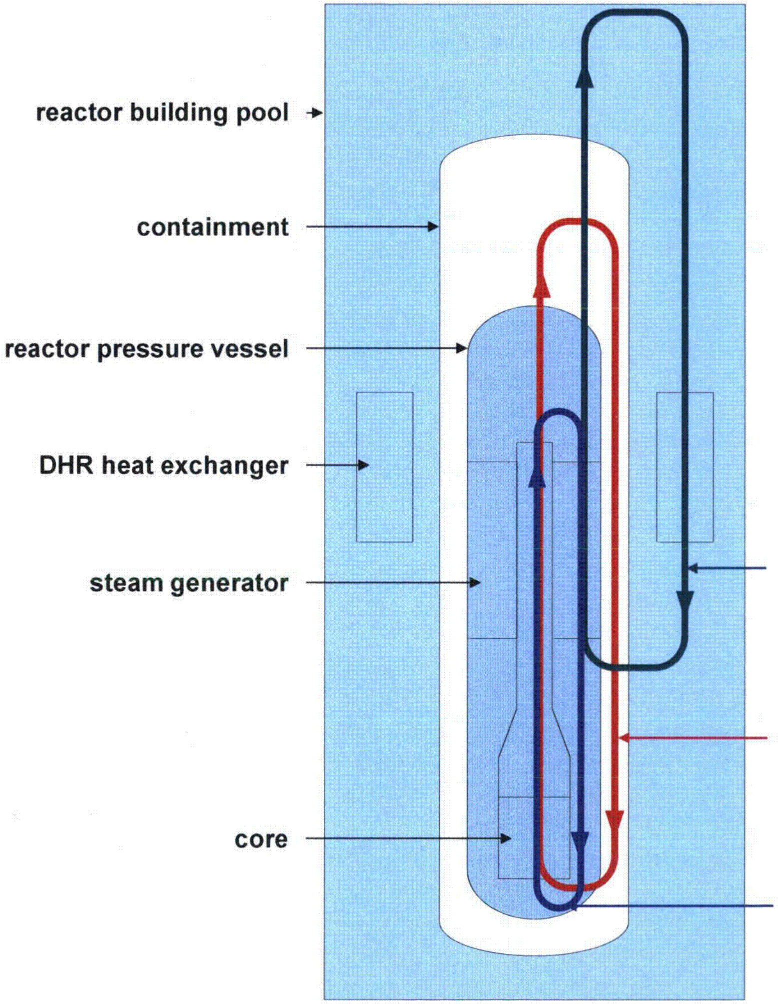
Passive Cooling Systems



- 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

CIV Approach

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Objectives

- Provide protection of public health and safety and the environment
  - provide high assurance of containment isolation
  - limit leakage through lines penetrating containment
  - assure availability of DHR
- Facilitate maintenance access to enhance reliability while minimizing personnel hazards
  - accessibility
  - ALARA
  - confined space

CIV Design Considerations

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Harsh Environment

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Space Limitations Inside CNV

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Containment Vessel Access

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Containment Penetrations

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Containment Isolation Valve Population

- NuScale has very few lines penetrating containment and, as a result, CIVs compared to other reactor designs

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None of the GDC 55 and 56 lines need remain open post-accident

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NuScale CIV Approach

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Concerns Being Addressed

- Reliability of valves
- Integrity of lines outside containment
- Common cause failure of isolation valves
- Environmental qualification
- Testability

Reliability of Valves

- Concern
  - high assurance of timely containment isolation is needed to meet the intent of GDCs 16 and 54

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Integrity of Lines Outside

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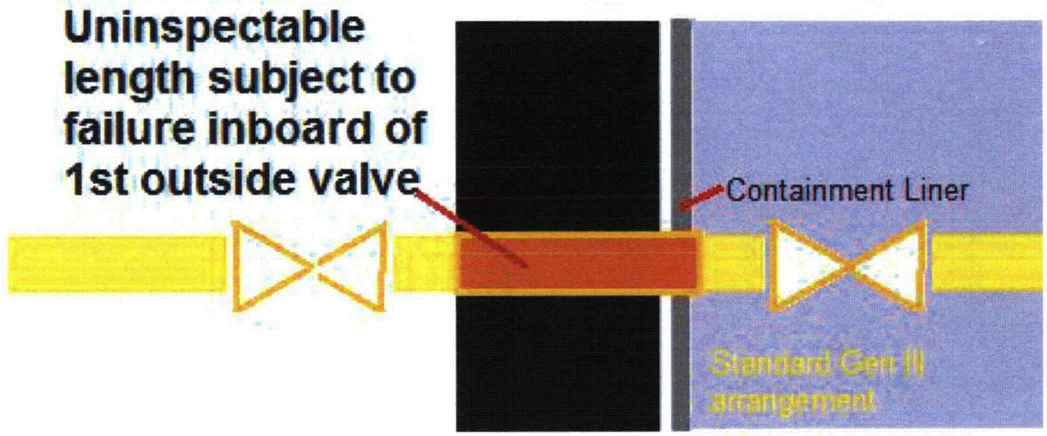
Integrity of Lines—Inspectability

- Current PWRs
  - many cannot readily inspect outside surface of containment lines between liner and first outside valve



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Common Cause Failure

- Concern
  - colocated CIVs may be susceptible to common cause failure (CCF) due to common environment, tornado missile, pipe whip, aging, etc.

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Environmental Qualification

- Concern
  - qualification to bounding environmental conditions is required to ensure valve reliability

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Testability

- Concerns
  - operability and surveillance
  - leak rate testing

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Potential Additional Features

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Potential Additional Feature

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Summary—CIV Approach

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NuScale DHR Approach

- Two passive containment barriers
  - closed system inside and outside containment

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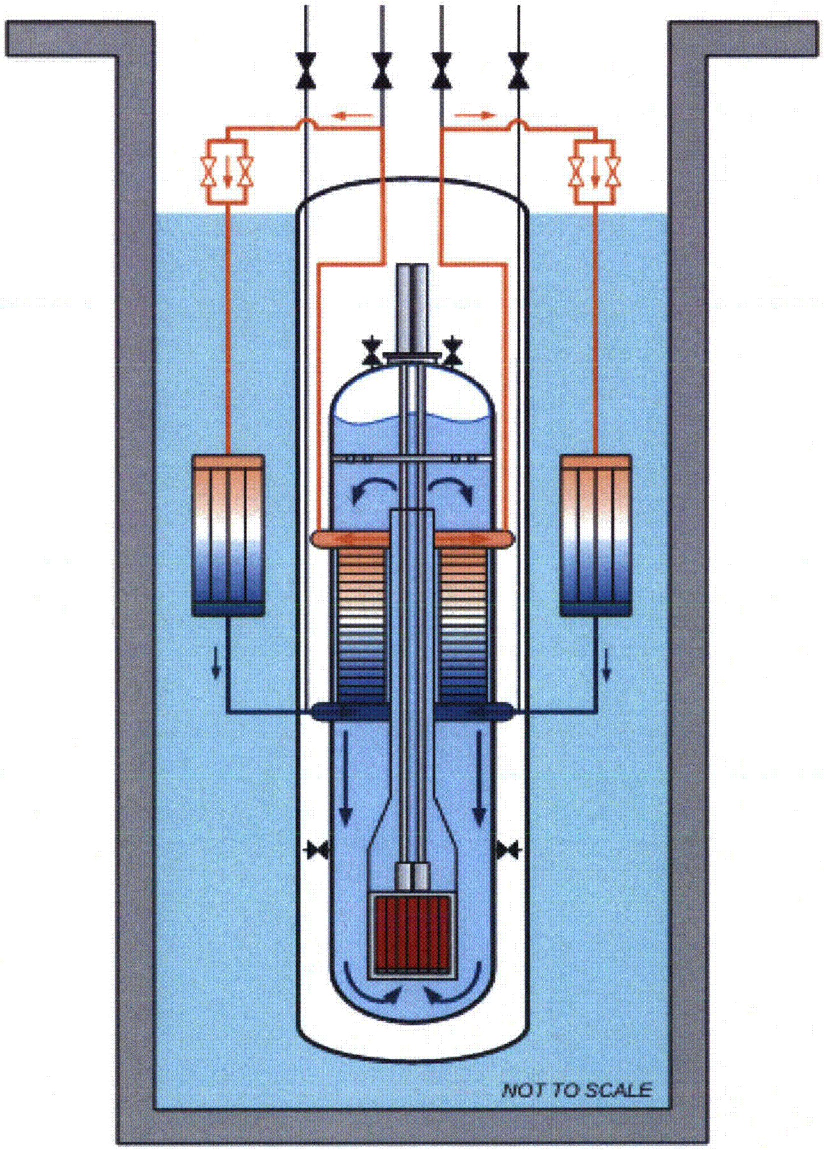

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DHR Design Considerations

- Closed (GDC 57) system

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Integrity of Barriers—Inside CNV

- Steam generators and associated piping comprise closed system

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  - primary system on outside, normally under compression

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  - Seismic I, Quality Group A
  - ASME Section III, Class 1

  – protected against missiles and other dynamic effects

  – designed to withstand normal and transient conditions

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Integrity of Barriers—Outside CNV

- DHR heat exchangers and associated piping comprise closed system

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  - Seismic I, Quality Group B
  - ASME Section III, Class 2

- – protected against missiles and other dynamic effects
- – no connecting normally open lines
- – designed to withstand normal and transient conditions

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Summary—DHR Approach

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Regulatory Approach

- All system piping penetrating containment complies with GDCs 55, 56, or 57, with the following exceptions

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- Complies with other regulatory requirements

Applicable Regulations

- GDCs 55 and 56
  - lines interfacing with RCPB or containment atmosphere
  - one locked closed or automatic isolation valve inside and one outside containment
  - as close to containment as practical

    "…unless it can be demonstrated that the containment isolation provisions for a specific class of lines, such as instrument lines, are acceptable on some other defined basis."
  - GDC 55 only

    "Other appropriate requirements to minimize the probability or consequences of an accidental rupture of (RCPB) lines or of lines connected to them shall be provided as necessary to assure adequate safety."

Applicable Regulations

- GDC 57
  - closed systems inside containment (not connected to the RCPB or containment atmosphere)
  - one locked closed, automatic, or remote-manual isolation valve outside containment
  - as close to containment as practical

Regulatory Approaches

- Containment isolation provisions can fall into one of three regulatory categories
  - GDC approaches
    - lines that meet the explicit GDC requirements
  - accepted alternate provisions
    - lines that differ from the explicit GDC requirements
    - acceptability of alternate isolation provisions documented generically in SRP Section 6.2.4
  - deviations from accepted approaches
    - lines that must be reviewed on a case-by-case basis to determine the acceptability of an alternate basis

Source: ABWR safety evaluation report (SER)

Accepted Alternate

- Approved approaches documented in SRP 6.2.4 acceptance criteria (AC)
  - Alternate provisions acceptable if applicant meets preconditions and design requirements specified in the AC
  - AC-1
    - acceptable provisions for instrument lines documented in Regulatory Guide 1.11
  - AC-4
    - lines in ESF, ESF-related, or safe shutdown systems
      - » acceptable with both CIVs outside containment
      - » requires leakage enclosure or designed to preclude breach through inboard CIV
      - » requires leakage detection for leakage from inboard CIV shaft or bonnet seals

Accepted Alternate

- AC-5
  - lines in ESF or ESF-related systems
    - » acceptable with only one CIV, which must be outside containment
    - » requirements of AC-4, plus
      - system reliability shown to be greater
      - system closed outside containment
      - single active failure can be accommodated
- AC-6
  - sealed closed barriers may be used in place of automatic isolation valves
    - » includes blind flanges and sealed closed isolation valves
- AC-15
  - specifies requirements for a closed system inside containment to meet GDC 57

Case-by-Case Deviations

- Where an accepted alternate is not available, applicant may justify alternate provisions on a case-by-case basis
  - in considering adequacy of approach, SERs typically address
    - reason for deviating, such as harsh environment, accessibility of valves for maintenance, or improved system reliability
    - adequacy of piping, valve design, and protection
    - single failure will not prevent isolation
    - isolation provisions commensurate with importance of isolating the line and system's function

Case-by-Case Deviations

- NuScale's application of precedent
  - SRP 6.2.4 provisions
    - not directly applicable, but provide insight on relevant considerations and appropriate design features
  - other design certification applications and SERs
    - approaches that NRC has previously accepted
    - establish the basis and safety for a particular deviation
  - "best match" for individual lines
    - consider type of line, function, reason for deviation, and isolation provisions for the relevant precedent
    - may need to extend precedent or draw from several cases

Goal: Minimize departure from current practice

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GDC Deviations

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***Note:** "Meet" means the AC is directly applicable per its terms and the line's design will be reviewed to it; "apply" means that the AC is not directly applicable but NuScale will use its provisions to support the acceptability of the deviation.

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GDC Deviations

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GDC Deviations

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CVC Lines

- One line each, RCPB interface
  - charging
  - pressurizer spray
  - letdown

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CVC Lines

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CVC Lines

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Reactor Degasification Line

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Reactor Degasification Line

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Containment Evacuation Line

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Containment Evacuation Line

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Service Air Line

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Service Air Line

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DHR System

- Two systems
- Closed system inside containment

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DHR System

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Feedwater, Main Steam, RCCW Lines

- Six lines total
- Closed inside containment

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Other Applicable Regulations

- No other GDC deviations anticipated
  - general requirements (e.g., GDCs 1, 2, 3, 4)
  - GDC 16—Containment design

    "Reactor containment and associated systems shall be provided to establish an essentially leak-tight barrier against the uncontrolled release of radioactivity to the environment."
  - GDC 54—Piping systems penetrating containment

    "Piping systems penetrating primary reactor containment shall be provided with leak detection, isolation, and containment capabilities having redundancy, reliability, and performance capabilities which reflect the importance to safety of isolating these piping systems."

Other Applicable Regulations

- Will comply with Three-Mile Island requirements (10 CFR 50.34(f)(2)(xiv))

"(A) Ensure all non-essential systems are isolated automatically by the containment isolation system,

(B) For each non-essential penetration (except instrument lines) have two isolation barriers in series,

(C) Do not reopen the containment isolation valves on resetting of the isolation signal,

(D) Utilize a containment set point pressure for initiating containment isolation as low as is compatible with normal operation,

(E) Automatically close all systems that provide a path to the environs on a high radiation signal."

DSRS

- Background
  - NuScale gap analysis
    - concluded SRP 6.2.4 should be modified
      - » modify for clarification: typical purge and vent systems (open path to environs) have special requirements not applicable to NuScale CE system
  - mPower DSRS review
    - DSRS adds "evacuation" along with purge and vent systems that have special requirements
    - based on mPower's design; not applicable to NuScale's CE

DSRS

- Proposed NuScale DSRS
  - SRP 6.2.4 may be used as-is
    - should include minor comment in Safety Review Matrix to clarify application to NuScale CE system
  - NuScale DSRS section 6.2.4 would facilitate review
    - consider modifying to reflect unique NuScale containment design and isolation considerations
    - consider new or revised acceptance criteria based on NuScale isolation basis and design features

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Results Achieved and Path

- Provided containment isolation conceptual design information
  - feedback on information needed or concerns?
- Provided regulatory approach and justification
- Discussed NuScale DSRS development
- Further engagements
  - potential workshop or paper on detailed valve design?