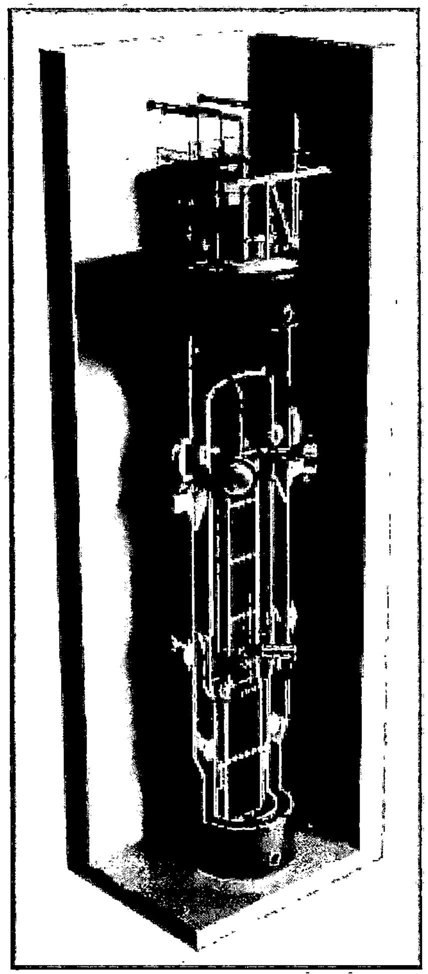
Enclosure:

"ACRS Full Committee Presentation: NuScale Topical Report – Non-Loss-of-Coolant Accident," PM-0320-69141, Revision 0

NuScale Nonproprietary

ACRS Full Committee Presentation



NuScale
Topical Report

Non-Loss-of-Coolant Accident

March 5, 2020

PM-0320-69141
Revision: 0

NUSCALE™ Power for all humankind

Template #: 0000-21727-F01 R5

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Outline

- Scope of non-LOCA LTR
- Non-LOCA events
  - Events and acceptance criteria
  - Interface to other methodologies
  - Factors controlling margin to acceptance criteria
- Development of non-LOCA EM
  - PIRT and gap analysis
  - Focus of NRELAP5 validation for non-LOCA
- General event analysis methodology
- Specific event analysis

Scope of Non-LOCA Topical Report

In Scope

- NRELAP5 system transient analysis of non-LOCA events
- Interface to subchannel and accident radiological analysis
- Short-term transient progression with DHRS cooling

Out of Scope

- SAFDLs evaluated in downstream subchannel analysis
- Accident radiological dose analysis
- Control rod ejection
- LOCA and valve opening events
- Peak containment pressure/temperature analysis
- Long term transient progression with DHRS
  - Riser uncovery
  - Return to power

Non-LOCA EM

EM applicable to NuScale Power Module plant design
Applicable initiating events:

- **Cooldown events**
  - Decrease in FW temperature
  - Increase in FW flow
  - Increase in steam flow
    Inadvertent opening of SG relief or safety valve
  - Steam piping failures (postulated accident)
  - *Loss of containment vacuum*
    Containment flooding
- **Heatup events**
  - Loss of external load
    Turbine trip
  - Loss of condenser vacuum
  - Closure of MSIV
  - Loss of non-emergency AC power
  - Loss of normal FW flow
  - Feedwater system pipe breaks (postulated accident)
  - *Inadvertent operation of DHRS*
- **Reactivity events**
  - Uncontrolled bank withdrawal from subcritical
  - Uncontrolled bank withdrawal at power
  - Control rod misoperation
    - Single rod withdrawal
    - Control rod drop
  - Inadvertent decrease in RCS boron concentration
- **Inventory increase event**
  - CVCS malfunction
- **Inventory decrease events**
  - Small line break outside containment (infrequent event)
  - Steam generator tube failure (postulated accident)

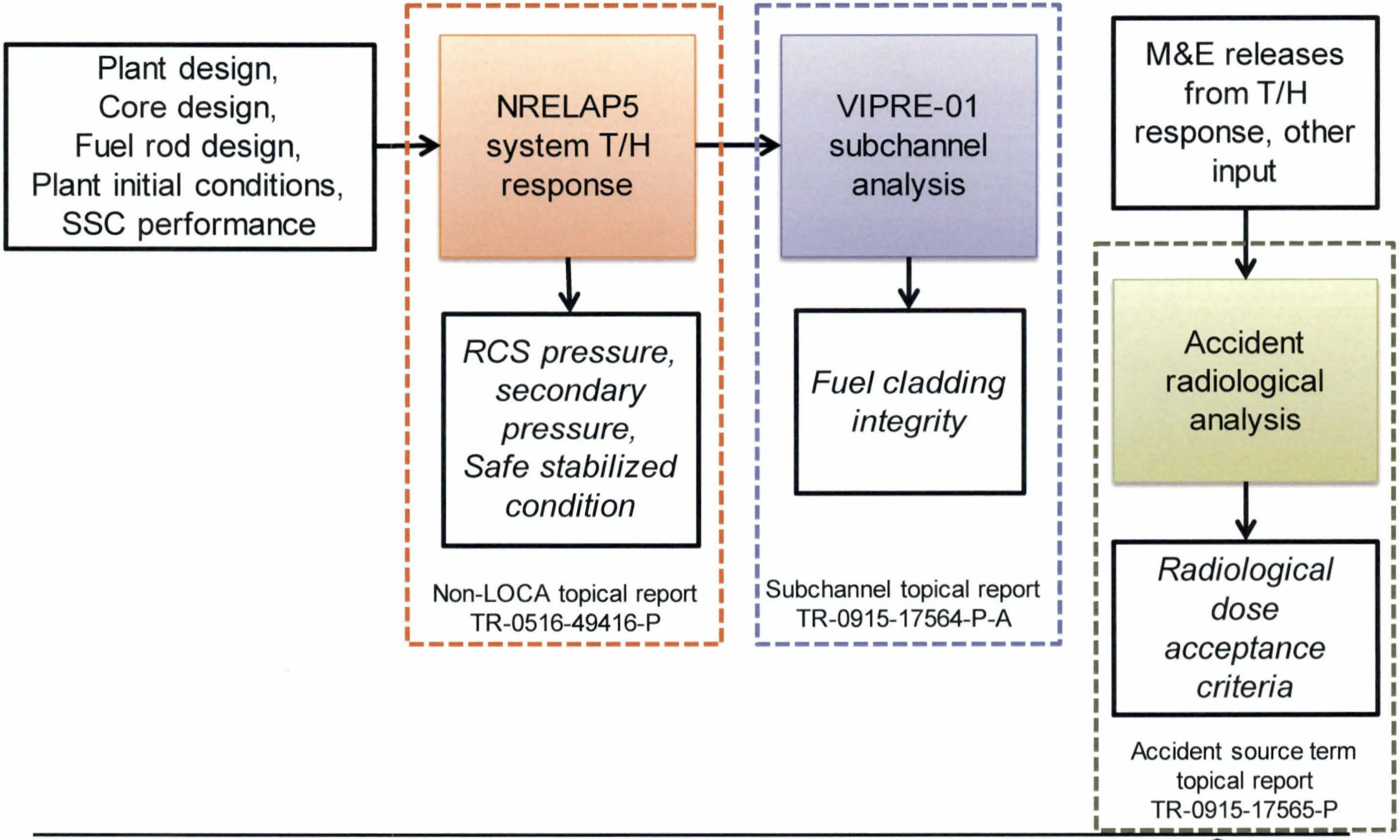
NuScale unique event

Non-LOCA Event Acceptance Criteria

Description	AOO Acceptance Criteria	Infrequent Event Acceptance Criteria	Accident Acceptance Criteria	Analysis
Reactor Coolant System Pressure (P_{design}= 2100 psia)	**≤ 110% of Design**	**≤ 120% of Design**	**≤ 120% of Design**	**Non-LOCA NRELAP5**
Steam Generator Pressure (P_{design}= 2100 psia)	**≤ 110% of Design**	**≤ 120% of Design**	**≤ 120% of Design**	**Non-LOCA NRELAP5**
Minimum Critical Heat Flux Ratio	> Limit	If limit exceed, fuel assumed failed (1)	If limit exceed, fuel assumed failed (1)	Subchannel
Maximum Fuel Centerline Temperature	< Limit	If limit exceed, fuel assumed failed (1)	If limit exceed, fuel assumed failed (1)	Subchannel
Containment Integrity	< Limits (pressure, temperature)	< Limits (pressure, temperature)	< Limits (pressure, temperature)	Containment P/T analysis
Escalation of an AOO to an accident (AOO) or Consequential loss of system functionality (IE or accident)?	**No**	**No**	**No**	**If other acceptance criteria are met**
Radiological Dose	Normal Operations	< Limit	< Limit	Normal or Accident radiological

(1) NuScale safety analysis methodologies developed to demonstrate fuel cladding integrity maintained.

Evaluation Models – General Non-LOCA Approach



Non-LOCA Events - Margin to Acceptance Criteria

Design characteristics governing non-LOCA event transient response and margin to acceptance criteria

- MCHFR: Limited by combination of high power, high pressure, high temperature conditions occurring around time of reactor trip, for reactivity insertion events
- Primary pressure: Protected by RSV lift
- Secondary side pressure: Limited by primary side temperature conditions
- Radiological release: MPS designed to rapidly detect and isolate based on measured conditions
- Establishing a safe, stable condition: MPS designed to trip, actuate DHRS to protect adequate inventory in at least 1 steam generator

Non-LOCA EM Development

- Non-LOCA evaluation model developed to perform conservative analyses, following intent of the RG 1.203 EMDAP and applying a graded approach
- Element 1 – Establish applicable transients and acceptance criteria, develop non-LOCA PIRT
- Element 2, 3, 4
  - Leverage NRELAP5 development, NRELAP5 assessments performed during LOCA evaluation model development.
    - Gap analysis performed to evaluate how high ranked phenomena are addressed
    - Focused on differences in high ranked PIRT phenomena between LOCA and non-LOCA
    - Additional NRELAP5 code validation performed focused on DHRS and integral non-LOCA response
  - Suitably conservative initial and boundary conditions applied for non-LOCA analyses
  - Sensitivity calculations used to demonstrate factors controlling margin to acceptance criteria

Non-LOCA PIRT Development

Event Types
Increased heat removal
Decreased heat removal
Reactivity anomaly
Increase in RCS inventory
Steam generator tube failure

SSCs Considered in PIRT	
Reactor coolant system	Main feedwater system
Containment vessel	Main steam system
Decay heat removal system	Chemical volume control system
Reactor pool	Containment evacuation system

Phase	Identification	RCS Response	DHRS Operation *	PIRT Figures of merit
1	pre-trip transient	higher flow levels at full power levels	inactive	CHFR RCS pressure
2	post-trip transition	transitional flow levels at transitioned power levels	startup	CHFR RCS, secondary, containment pressures
3	stable natural circulation	lower flow levels at decay power levels	fully effective	CHFR RCS mixture level Subcriticality

* If DHRS actuated by protection system

- Different non-LOCA events involve different plant systems and responses
- PIRT developed considering all non-LOCA event types and important SSCs
- Short-term response divided into 3 generic phases with associated FoM

NRELAP5 Applicability for Non-LOCA

After non-LOCA PIRT developed, gap analysis performed to determine how to address high-ranked phenomena:

- Validation performed as part of NRELAP5 assessment for LOCA evaluation model
- Additional validation or benchmark for non-LOCA
- Conservative input
- Subchannel analysis

Key areas identified from gap analysis for short-term non-LOCA analysis:

- DHRS modeling and heat transfer
  - NRELAP5 validation against KAIST tests; NIST-1 SETs HP-03, HP-04
  - NPM sensitivity calculations
- Steam generator modeling and heat transfer
  - NRELAP5 validation against SIET-TF1, SIET-TF2 tests
  - NPM sensitivity calculations
- Reactivity event response
  - NRELAP5 benchmark against RETRAN-3D
- NPM non-LOCA integral response
  - NRELAP5 validation against NIST-1 IETs NLT-2a, NLT-2b, NLT-15p2

Overall conclusion: NRELAP5 code, with NPM system model, is applicable for calculation of the NPM non-LOCA system response

Non-LOCA Analysis Process

Topical report Section 4

1. Develop plant base model NRELAP5 input (geometry, control and protection systems, etc)
2. Adapt NRELAP5 base model as necessary for specific event analysis and desired initial conditions
3. Perform steady state and transient analysis calculations with NRELAP5
4. Evaluate results of transient analysis calculations:
   - Confirm margin to maximum RCS pressure acceptance criterion
   - Confirm margin to maximum SG pressure acceptance criterion
   - Confirm appropriate transient run time execution to demonstrate safe, stabilized condition achieved
5. Identify cases for subchannel analysis and extract boundary conditions (if applicable)
   - Conservative bias directions:
     - Maximum reactor power
     - Maximum core exit pressure
     - Maximum core inlet temperature
     - Minimum RCS flow rate
   - NRELAP5 CHF calculations for dummy hot rod may be used as a screening tool to assist analysts in determining limiting cases to be evaluated in downstream subchannel analysis
6. Identify cases for radiological analysis (if applicable)
   - Maximum mass release case
   - Maixmum iodine spiking case

Non-LOCA Methodology

General Methodology (Section 7.1):

- Steady-state conditions
- Treatment of plant controls
- Loss of power
- Single failure
- Bounding reactivity parameter input
- Biasing of other parameters: initial conditions, valve characteristics, analytical limits and response times
- Operator action

Event-specific Methodology (Section 7.2)

- Description of event initiation and progression
- Acceptance criteria 'of interest'
- Limiting single failure, loss of power scenarios, or need for sensitivity calculations
- Initial condition biases and conservatisms, or need for sensitivity calculations
- Tabulated representative results of sensitivity calculations

Example analysis results provided in Section 8

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Conclusions

- Non-LOCA system transient evaluation model developed following a graded approach in accordance with guidance provided in RG 1.203
- Applies to NPM-type plant design natural circulation water reactor with helical coil SG and integral pressurizer
- NRELAP5 used to simulate the system thermal-hydraulic response
  - Demonstrate primary and secondary pressure acceptance criteria are met
  - Demonstrate safe, stabilized condition achieved
- System transient results provide boundary conditions to downstream subchannel and radiological analyses

Acronyms

- AOO – Anticipated Operational Occurrences
- CNV – Containment Vessel
- CVCS – Chemical and Volume Control System
- DHRS – Decay Heat Removal System
- ECCS – Emergency Core Cooling System
- EM – Evaluation Model
- EMDAP – Evaluation Model Development and Assessment Process
- FW – Feedwater
- FWIV – Feedwater Isolation Valve
- IET – Integral Effects Test
- KAIST – Korea Advanced Institute of Science and Technology
- LOCA – Loss of Coolant Accident
- MCHFR – Minimum Critical Heat Flux Ratio
- MPS – Module Protection System
- MSIV – Main Steam Isolation Valve
- MSS – Main Steam System
- NIST-1 – NuScale Integral System Test-1
- NPM – NuScale Power Module
- PIRT – Phenomena Identification and Ranking Table
- RCS – Reactor Coolant System
- RPV – Reactor Pressure Vessel
- RSV – Reactor Safety Valve
- RVV – Reactor Vent Valve
- SET – Separate Effects Test
- SG – Steam Generator
- SSC – Structures, Systems, and Components

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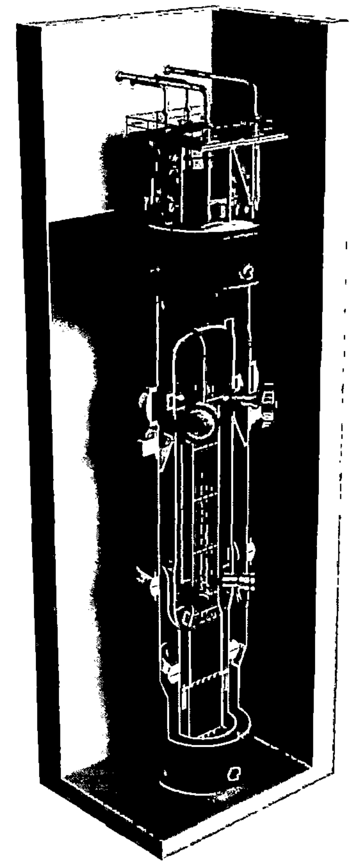

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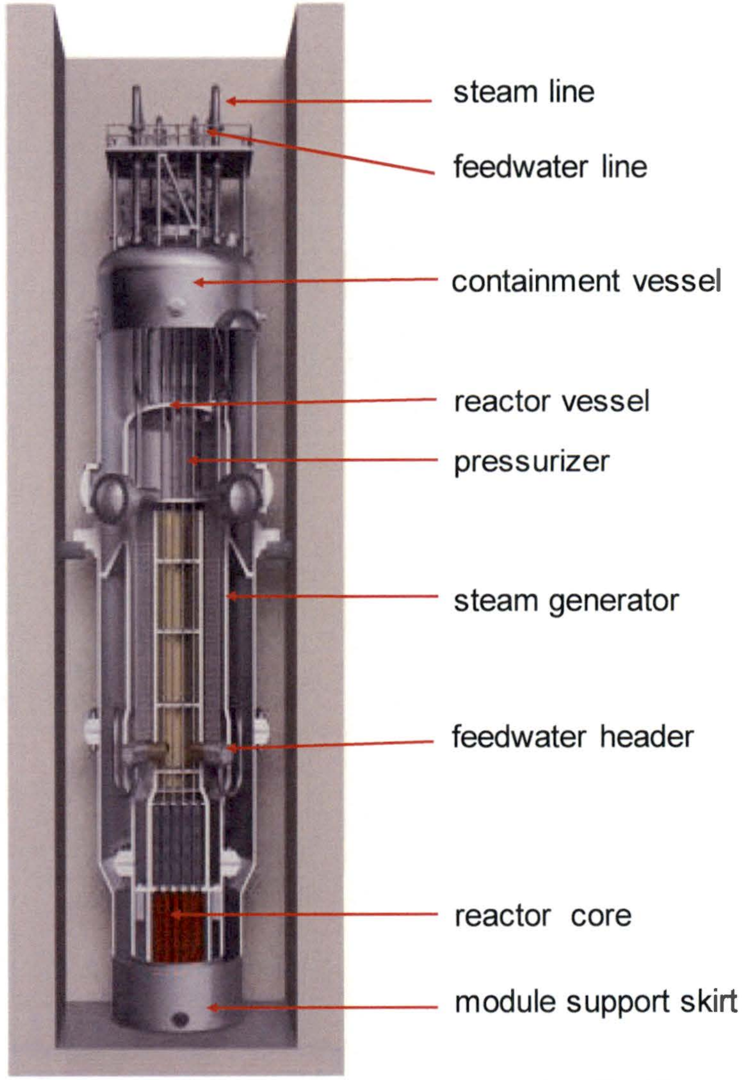
Additional Material for Public Presentation

Previously presented background material

Power Module Overview

Integral Pressurized Water Reactor

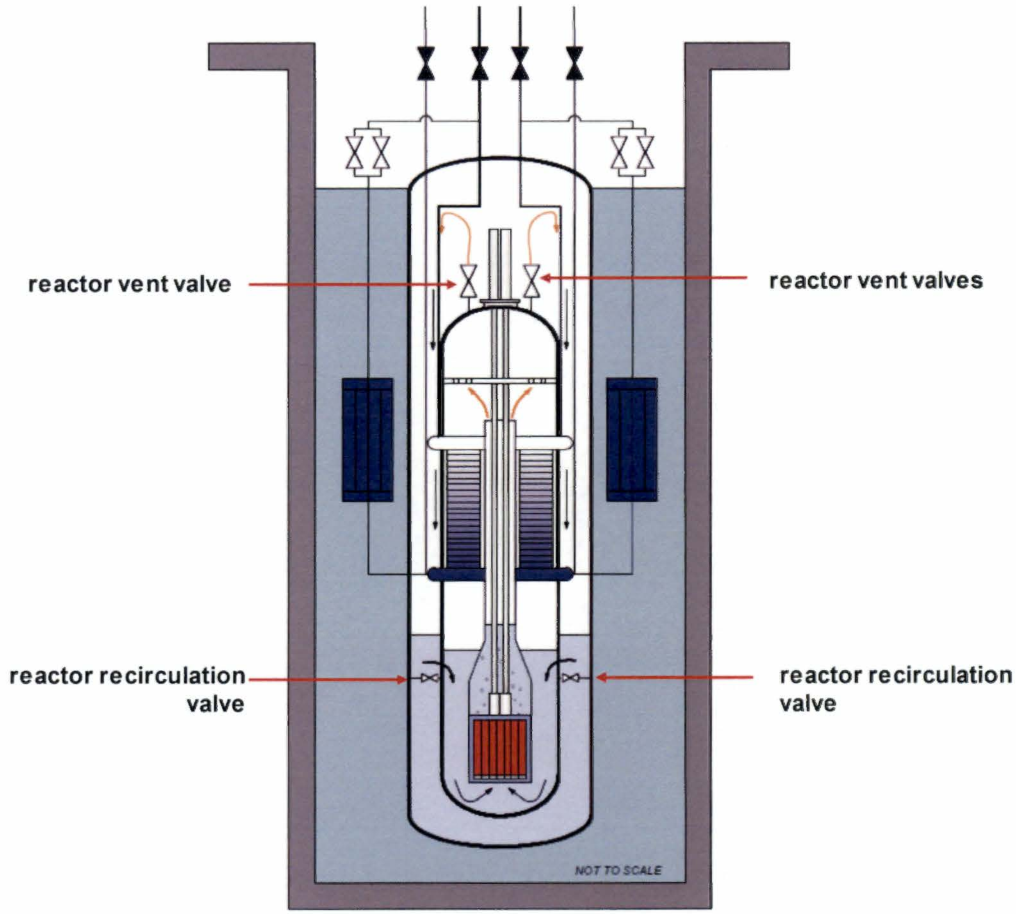
- Core, steam generator and pressurizer in one vessel
- Integrated reactor design, no large-break loss-of-coolant accidents
- Reactor coolant system operated in single phase (liquid) density driven flow
- Safety decay heat removal systems are passive and fail safe
- Module protection system designed to automate event mitigation actuations (no operator actions)



ECCS

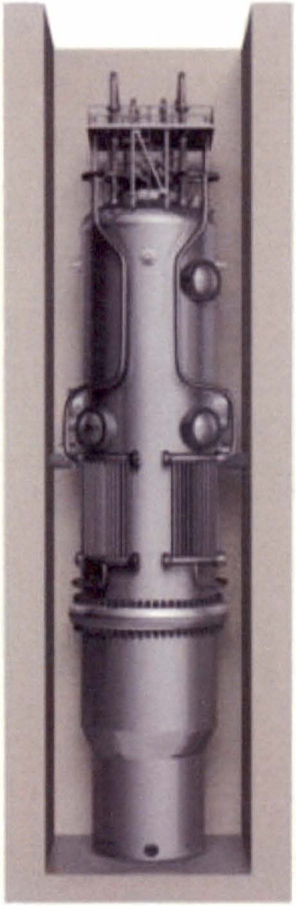
Emergency Core Cooling System

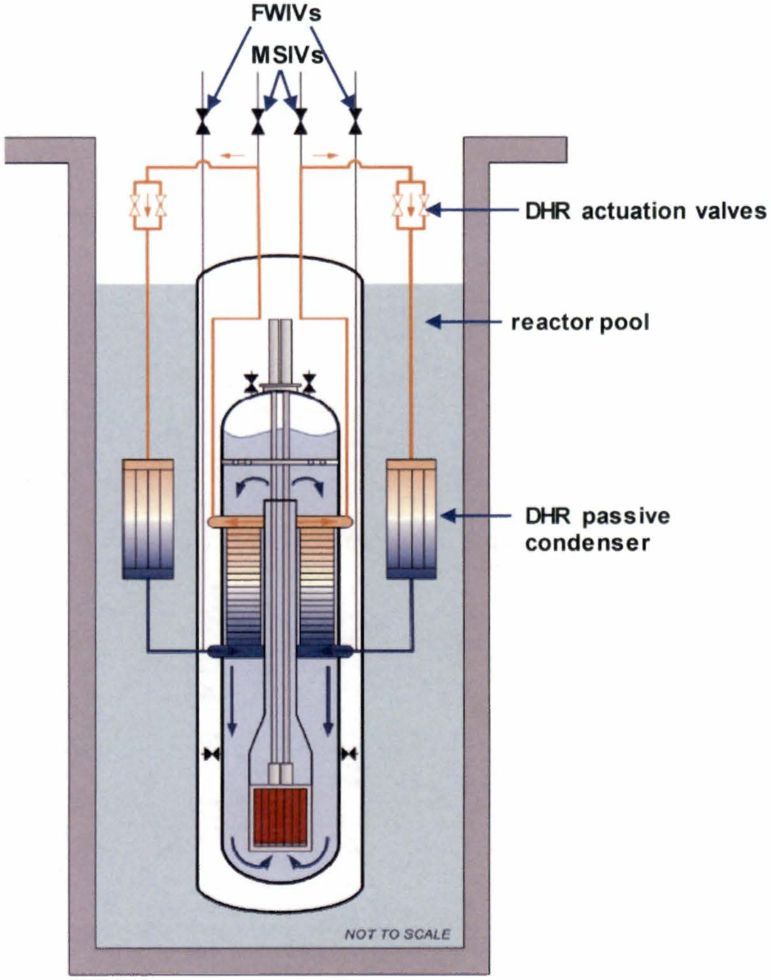
- ECCS valves open to a boiling/condensing circulation flow path to transfer decay and residual heat to reactor pool
  - Liquid from containment vessel enters RCS through reactor recirculation valves
  - Vapor vented from RCS to containment vessel through reactor vent valves
  - Steam condenses on inside surface of containment vessel
  - Heat transfer through vessel walls to the reactor pool
- Actuation Signals: High CNV level, 24hr loss of AC power
- Fail safe: ECCS valves open on loss of DC power



Decay Heat Removal System (DHRS)

- Removes heat after loss of normal cooling
- Boiling/condensing loop
- Two redundant trains
- Redundant actuation and isolation valves for each train
- Initiates on:
  - Loss of power
  - Loss of cooling indication (ESFAS Signal)





Deterministic Event Mitigation

Module Protection Functions

Reactivity Control

- Reactor trip
- CVCS/Demineralized Water Isolation

RCS and Secondary Inventory Control

- Containment Isolation
- Secondary Isolation

Heat Removal

- DHRS Actuation
- ECCS Actuation

Subcooling

- Reactor trip

Event Mitigation

Increase in heat removal transients

- Reactor trip   Secondary Isolation

Decrease in heat removal transients

- Reactor trip   DHRS Actuation

Reactivity and power transients

- Reactor trip   Demineralized Water Isolation

Increase in RCS inventory transients

- Reactor trip   CVCS Isolation

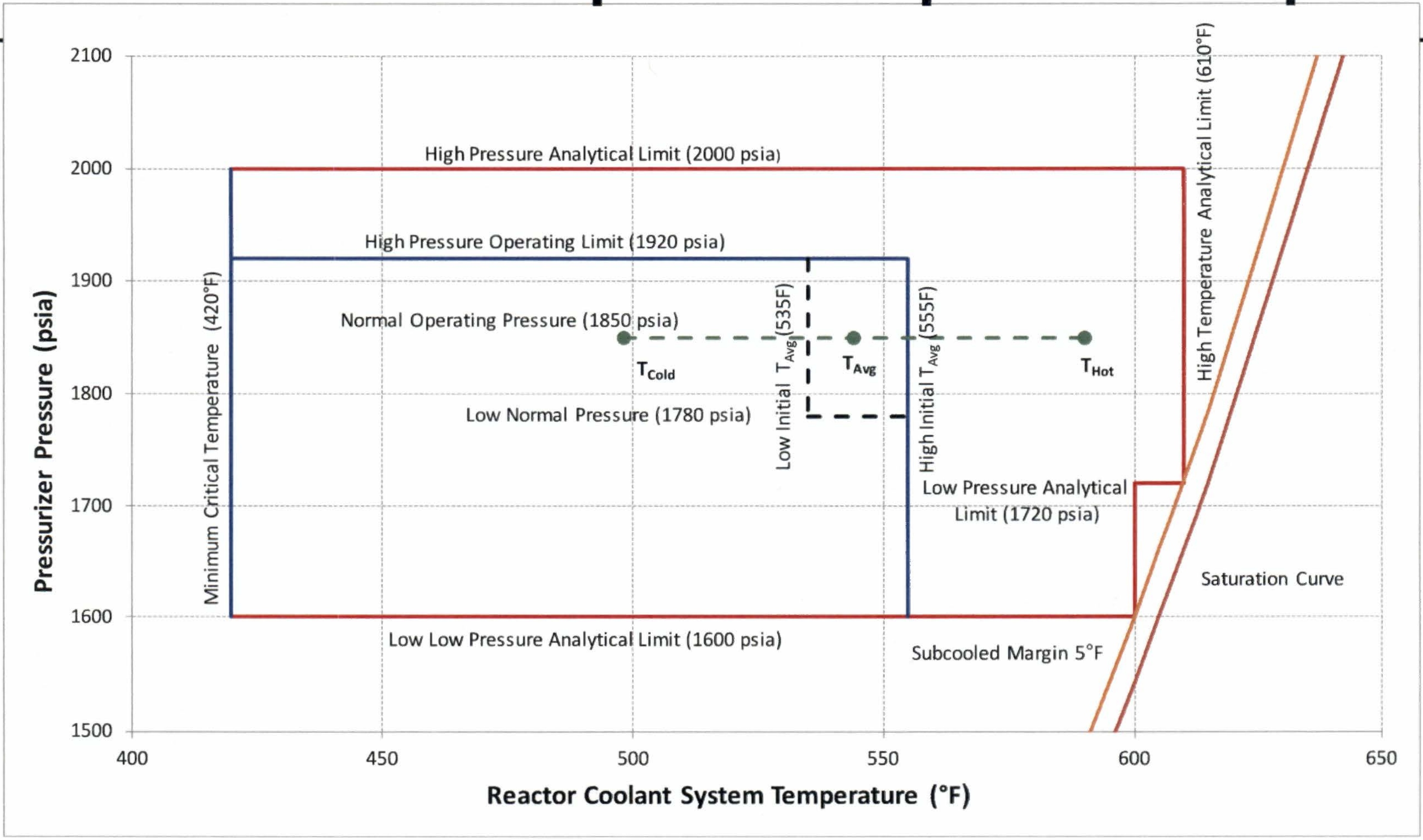
Decrease in RCS inventory transients

- Reactor trip   CNV Isolation
  ECCS actuation

Stability

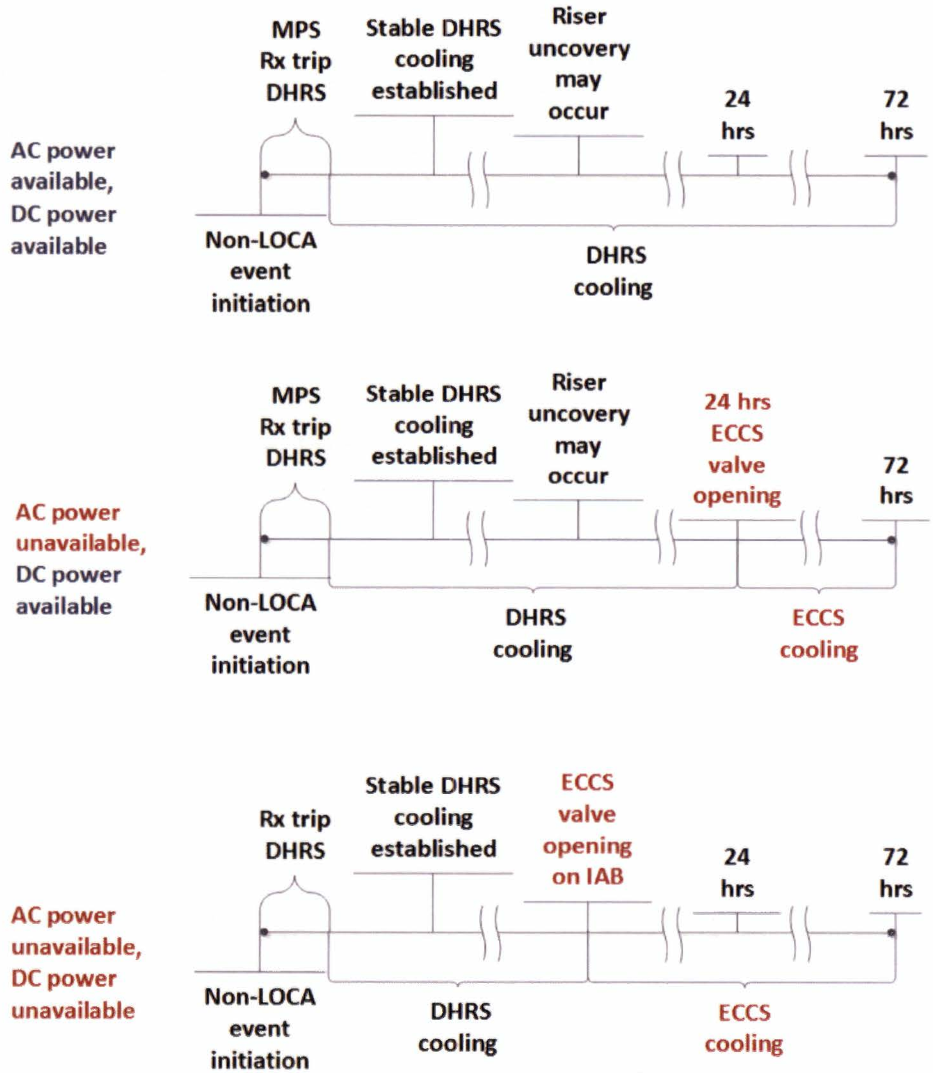
- Reactor trip

Pressure vs. Temperature Operation Map



- Module protection system (Ch. 7, red)
- Technical specification LCOs (Ch. 16, blue)

Loss of Power – Non-LOCA Event



- Availability of AC, DC power affects whether ECCS valves actuate, and what time they open

5.1 – Summary Description