Study of Regulatory Cases for Passive Containment Heat Removal Systems in SMR

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Design of passive containment heat removal system in SMR

❖ NuScale containment heat removal system

- The containment heat removal system is equipped with two independent and redundant passive safety systems. ***(DHRS, ECCS)***
- Containment heat removal based on heat transfer between the reactor pool and the outer wall of the containment vessel (CV).
- A new safety injection method recirculating cooling water by condensing steam on the inner wall of the containment during a DBA.

Fig. 1. Process of NuScale Containment Long-term cooling

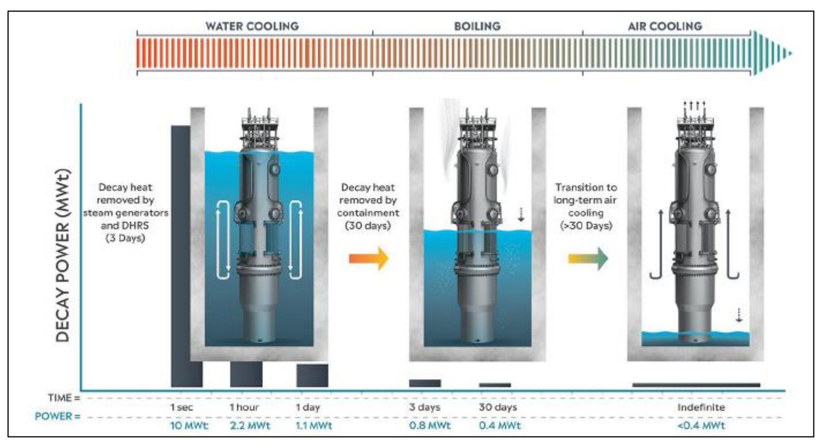
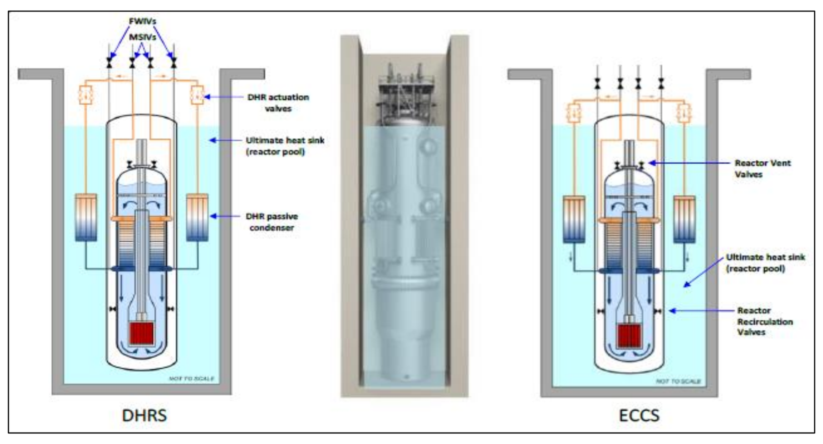


Fig. 2. Diagrams of the DHRS & ECCS

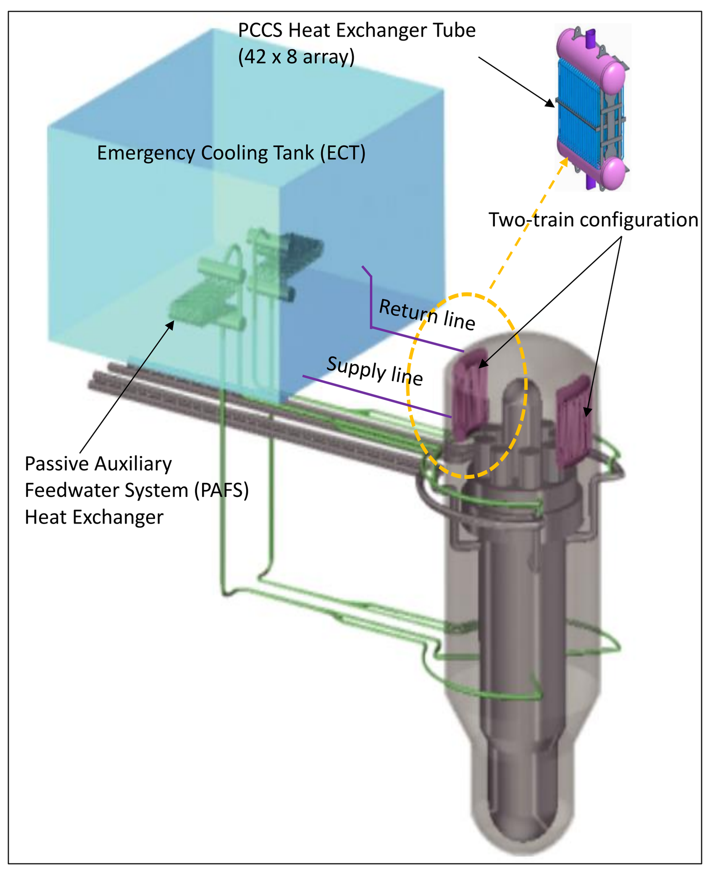


❖ i-SMR Passive containment cooling system

Table I : Containment Heat Removal Systems, NuScale VS i-SMR

Comparison of Containment Heat Removal Systems between NuScale and i-SMR		
	NuScale	**i-SMR**
Containment heat removal system	*Integrated with ECCS*	*Independent PCCS*
Ultimate heat sink	*Reactor pool*	*Emergency Cooling Tank (ECT) connected via natural circulation loop*
Passive safety systems	*DHRS + ECCS*	*ECCS + PCCS*
Long-term cooling	*Condensate forms a natural recirculation path when it exceeds valve height*	*Natural circulation driven by density difference; no valves in the flow path*
Heat Removal mechanism	*During ECCS operation, steam condenses on the inner containment wall; heat conducts through the wall to the reactor pool*	*Steam condenses on the cold outer surface of PCCS heat exchanger; heated coolant naturally circulates to the emergency cooling tank*

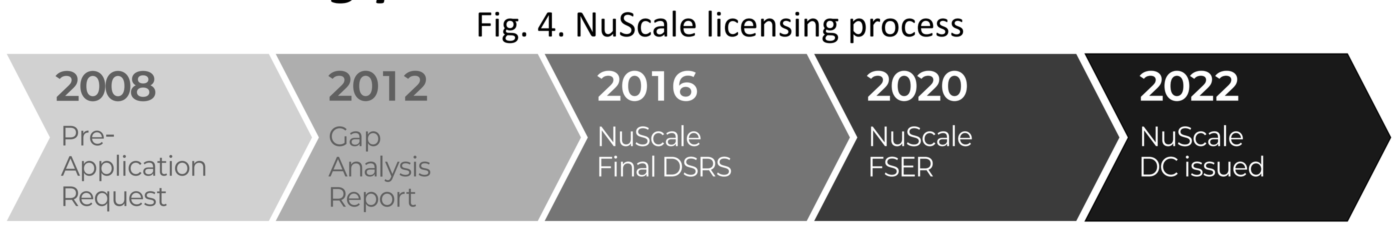
Fig. 3. Component of i-SMR PCCS



Regulatory case of NuScale

❖ NuScale licensing process

Fig. 4. NuScale licensing process



❖ Standard review plan (SRP)

- The acceptance criteria for containment heat removal systems are stipulated in SRP 6.2.2, which requires compliance with GDC 38, 39, 40, and 10 CFR 50.46(b)(5).

Table II : Acceptance criteria of SRP section 6.2.2

	Acceptance criteria of SRP section 6.2.2
GDC 38	**Containment heat removal system.**
GDC 39	**Inspection of the containment heat removal system.**
GDC 40	**Test of the containment heat removal system.** *The containment heat removal system shall be designed to permit appropriate periodic pressure and functional testing to assure **(1) the structural and leaktight integrity of its components, (2) the operability and performance of the active components of the system, and (3) the operability of the system as a whole, and under conditions as close to the design as practical the performance of the full operational sequence that brings the system into operation**, including operation of applicable portions of the protection system, the transfer between normal and emergency power sources, and the operation of the associated cooling water system.*
10 CFR 50.46 (b)(5)	**Ensure long-term cooling capability, including Net Positive Suction Head (NPSH), in the presence of debris following a LOCA.**

❖ Gap analysis

- NuScale PCCS utilizes passive heat removal system, lead to the conclusion in its NRC submittal that periodic functional ***testing*** is unnecessary.

Table III : NuScale's basis for departure

US NRC Regulatory Requirement (GDC 40)	NuScale's basis for departure
Structural and leak tight integrity of components	NuScale PCCS consist of steel containment vessel wall and the surrounding heat transfer medium.
Operability and performance of components	Passive design removes heat **without reliance on electrical power, valve actuation, or pump driven coolant supply,** operability is inherent
Ensures operability and design for power interruption conditions.	

❖ Design specific review standard (DSRS)

- NRC reviewed the gap analysis report and developed a DSRS (based on SRP) tailored to NuScale design.
- Due to NuScale integral and multi-module design, the DSRS includes GDC 5.
  - ➢ *Structures, systems, and components critical to safety must not be shared among different nuclear power plant units unless it can be demonstrated that such sharing does not significantly compromise safety functions.*

Table IV : Comparative analysis of SRP and DSRS review area

SRP review area	DSRS review area
Analysis of outcomes resulting from a single component malfunction	*Analysis of outcomes resulting from a single component malfunction*
Evaluation of the available net positive suction head (NPSH) for the pumps of the ECCS and the Containment Heat Removal System.	*Proposed design provisions and plans for periodic in-service inspection and operability testing of systems and components*
Heat removal capability of the containment spray system	*Ultimate heat sink design review*
Heat removal capability of the RHRS and containment fan cooler heat exchangers	*Assessment of long-term cooling capability loss due to debris generated by a LOCA*
Evaluation of potential surface fouling of the fan-cooler, recirculation, and RHRS heat exchangers and its effect on exchanger performance	*Review of Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC)*
Design rules and proposed plans for periodic inspection and operability testing of each system and component	*Evaluation of potential contamination on both the external and internal surfaces of the containment vessel and its impact on containment heat removal performance*

❖ Standard design certification application

- NuScale Power submitted its standard design certification application, including topical reports and a Final Safety Analysis Report with 17 exemption requests, one of which pertains to ***GDC 40 in 10 CFR 50(a).***
  - ➢ *The basis for this exemption is that inspections performed in accordance with GDC 39 would ensure operability and performance without the need for the periodic pressure and performance tests required by GDC 40. In FSAR Section 6.2.2, NuScale contends that by satisfying GDC 38, GDC 39, and 10 CFR 50.46(b)(6), the application of GDC 40 can be waived.*

❖ Final safety evaluation report (FSER)

- The NRC approved that compliance with GDC 39 allows NuScale containment heat removal system to ensure operability without the periodic performance testing required by GDC 40.
- NuScale apply Principal Design Criterion (PDC) 38 in lieu of GDC 38.
  - ➢ *GDC 38 is rooted in conventional Light water reactor (LWR) design, whereas PDC 38 reflects NuScale design by adopting passive rather than active cooling systems.*
- NRC found that NuScale system meets all applicable regulatory requirements, maintains functionality under single-failure conditions, and ***can effectively manage debris and chemical byproducts generated during Loss of coolant accident (LOCA) - 10 CFR 50.46(b)(5)***. Consequently, NuScale granted the standard design certification.

Domestic regulatory case

Fig.5. Diagram of SMART100 CPRSS

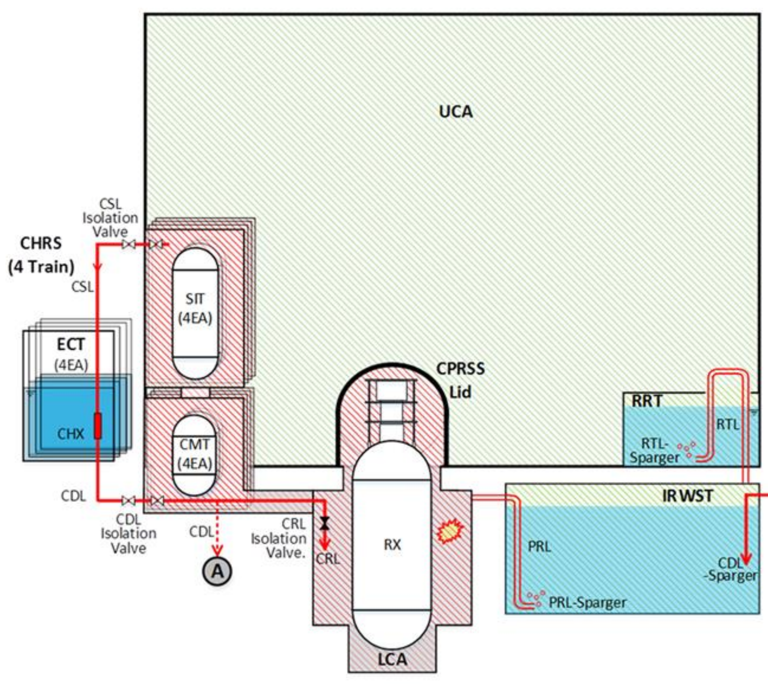


Table V : Regulatory challenges associated with SMART100

Regulatory challenges associated with SMART100
$P_{Design} > P_{Predict}$ (Containment pressure) Pressure doesn't sufficiently decrease within 24 hours.
▼
Satisfy **10 CFR 100.11 & Article 23** of the domestic technical standards.
Additional verification ▶ Pressure reduction, dose assessment, structural integrity
Secured safety margins during a DBA (22.6–28.4%) and pressure controlled within 72 hours
Radiation levels remained below regulatory limits ▶ Confirming containment functionality

➢ The Containment pressure and radioactivity suppression system (CPRSS) of SMART100 cools the containment building by condensing steam using a vertically submerged condenser heat exchanger and the refueling water storage tank inside the reactor building.

Expected regulatory issues for PCCS of i-SMR

- The domestic review criteria for containment heat removal systems in conventional nuclear power plant are specified in Korea Institute of Nuclear Safety(KINS) Safety Review Guidelines for LWRs, Section 6.2.2.

Table VI : Regulatory similarity between KINS and NRC

KINS Safety Review Guidelines for LWR		NRC	Contents
Regulations on Technical Standards for Nuclear Reactor Facilities, Etc.	***Article 23***	***GDC 38***	*Require that the containment heat removal system rapidly reduce containment pressure and temperature following DBA.*
	Article 23	***GDC 39 | GDC 40***	*Inspections and tests of components*
	Article 24	***10 CFR 50.46 (b)(5)***	*Ensuring long-term cooling*

- Article 41 : Regular testing is intended to verify the performance ***of active components***.
  - ➢ *However i-SMRs, the PCCS removes heat during an accident purely through natural circulation of the coolant, without relying on electric power, valve actuation, or pump-driven supply.*
  - ➢ ***Passive loops are continuously open, it is not feasible to conduct in-service tests to verify functionality in the same manner as active systems.***

Conclusions

- Due to NuScale design characteristic , the NRC approved an exemption from periodic testing, those for assessing surface degradation or fouling etc. were sufficiently effective during inspection, upon evaluating the exemption criteria outlined in 10 CFR 50.12, periodic test is impractical for such passive systems.
- In the upcoming licensing process of i-SMR, regulatory attention is expected to center on the applicability or exemption of periodic testing requirement.
  - ➢ Article 11 provides a legal basis for exemption, but lacks specific implementation procedures.