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

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## 1. Introduction

In the development of Innovative-Small Modular Reactors (i-SMR) adopting a new, passive containment heat removal system, a regulatory gap arises when attempting to apply existing requirements designed to ensure the operability of active heat removal systems. To address these regulatory challenges associated with Passive Containment Cooling Systems (PCCS) in advanced SMR designs, it is critical to examine and analyze relevant regulatory precedents, most notably the NuScale, which proactively underwent design certification. During the licensing process, NuScale Power sought an exemption from General Design Criterion (GDC) 40, which mandates testing of the containment heat removal system. Following a thorough review, the Nuclear Regulatory Commission (NRC) determined that the justification provided adequately satisfied the relevant requirements and subsequently granted approval.

In this study, US and domestic regulatory cases were studied to analyze the regulatory gaps associated with the heat removal system of NuScale and SMART 100, which have received design certificate and standard design approval respectively. Based on the former regulatory cases the expected regulatory issues for the PCCS of i-SMR in licensing processes were deduced.

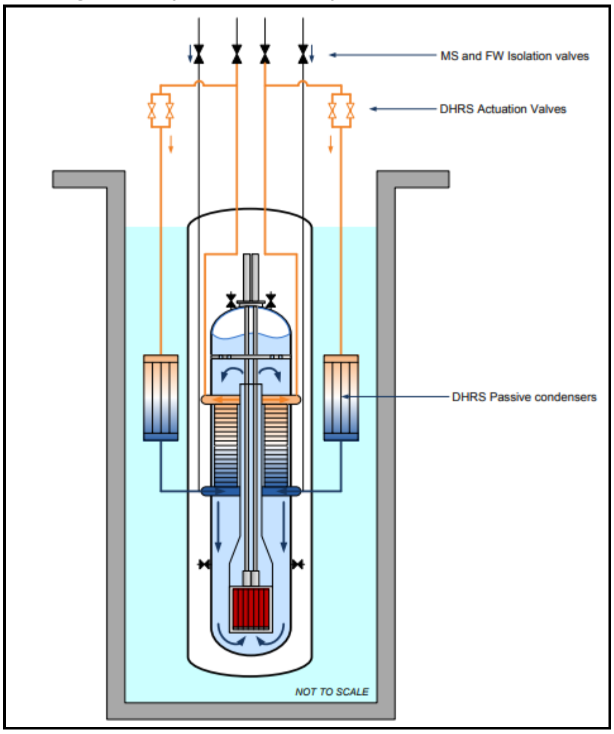
## 2. Designs of Passive Containment Heat Removal System in SMR

### *2.1 NuScale containment heat removal system*

NuScale Reactor Vessel (RV) is submerged in a water tank, and an innovative design concept has been developed to simultaneously perform emergency core cooling and containment heat removal based on heat transfer between the reactor pool and the outer wall of the containment vessel. In addition, a new safety injection method has been adopted to recirculate cooling water into the reactor vessel by condensing steam released from the reactor vessel on the inner wall of the steel containment vessel in the event of a Design Basis Accident (DBA) [1].

In NuScale the operation of the Emergency Core Cooling System (ECCS) involves opening valves at the top of the RV, allowing steam to be released into the containment. The steam then condenses on the inner surface of the Containment Vessel (CV) through condensation heat transfer. The condensed liquid accumulates at the lower part of the reactor pool. Once the water level exceeds the recirculation valve threshold, the recirculation valve opens, establishing a natural circulation path where water from the containment re-enters the core. This process effectively reduces both pressure and temperature inside the containment while simultaneously facilitating heat removal from the containment.

Fig. 1. Decay heat removal system of NuScale




### *2.2 i-SMR containment heat removal system*

The containment heat removal system of i-SMR is referred to as the PCCS. Unlike traditional designs that maintain the RV in a dry environment, this system incorporates heat exchangers inside the steel CV to facilitate steam condensation. Under accident conditions, the cooling water within the heat exchanger circulates naturally, transferring heat to the ultimate heat sink. The PCCS consists of a supply pipe, heat exchangers located inside the containment, return pipes, and an Emergency Cooling water Tank (ECT) [2].

During DBA, steam released into the containment contacts the cold outer surface of the PCCS heat exchanger, leading to condensation. The heated coolant inside the PCCS heat exchanger circulates naturally between the heat exchanger and the ECT due to density differences. This process facilitates the transfer of residual heat to the ECT, which serves as the ultimate heat sink, ensuring efficient passive cooling of the containment.

Fig. 2. PCCS layout of i-SMR

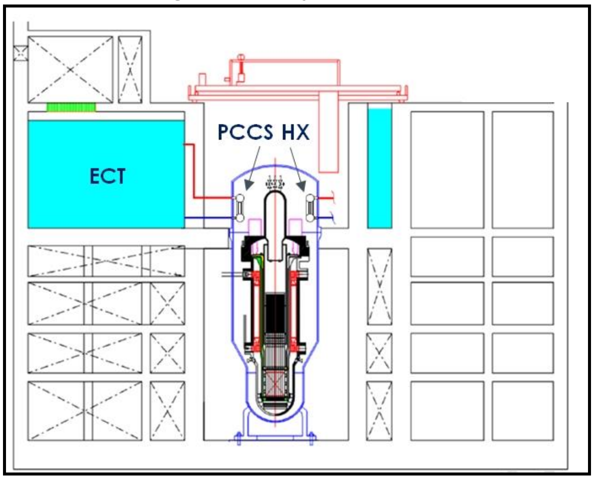
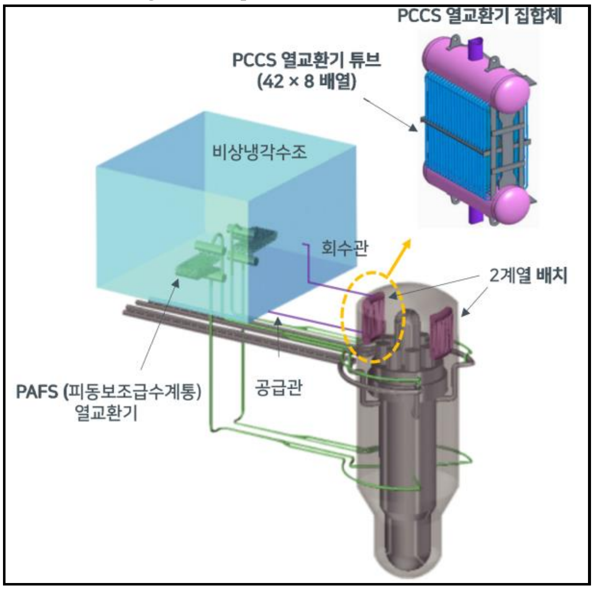



Fig. 3. Component of i-SMR PCCS




## 3. Regulatory Case of NuScale

In this Study, the regulatory case of the NuScale was studied since it represents the sole example to complete the entire review processes of design certification.

### *3.1 NuScale licensing process*

Beginning in 2016, the NRC and NuScale conducted pre-licensing reviews, highlighting the design differences between traditional large reactors and SMRs. Based on these differences, NuScale published a Gap Analysis Report [3]. In turn, the NRC utilized this report to develop Design Specific Review Standard (DSRS) guidance for the NuScale, building on the existing SRP. In December 2016, NuScale submitted a design certification application to the NRC, including its Final Safety Analysis Report (FSAR). In August 2020, the NRC issued its Final Safety Evaluation Report (FSER).

Fig. 4. NuScale licensing process


### *3.2 Conventional review plan*

The Standard Review Plan (SRP), an NRC regulatory document, is part of the nuclear safety legislation codified under Title 10, Chapter 1 of the Code of Federal Regulations (10 CFR). For existing large-scale nuclear power plants, reviews are conducted based on NUREG-0800 (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 1 provides a summary of the acceptance criteria found in SRP Section 6.2.2 [4]. Ultimately, these criteria define the requirements to ensure that, in the event of a Loss of coolant accident (LOCA), the containment heat removal system lowers containment pressure and temperature to acceptable levels, thereby safeguarding the safety function of containment. Since newly developed SMR differ in design from conventional water-cooled reactors, the existing SRP may not be directly applicable, indicating a need to revise certain areas of the review guidelines.

Table I: Acceptance criteria of SRP section 6.2.2

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|---|---|
| Acceptance Criteria | **GDC 38**<br>Containment heat removal system.<br><br>**GDC 39**<br>Inspection of the containment heat removal system.<br><br>**GDC 40**<br>Test of the containment heat removal system.<br><br>**10 CFR 50.46(b)(5)**<br>Ensure long-term cooling capability, including Net Positive Suction Head (NPSH), in the presence of debris following a LOCA. |

### *3.3 Gap analysis*

NuScale PCCS consists of a steel containment vessel and its surrounding heat transfer medium. This passive design ensures effective heat removal without relying on active components such as electrical power, valve actuation, or pump-driven coolant supply. Consequently, NuScale submitted a Gap Analysis Report to the NRC stating that no periodic functional or operational testing is required.

*3.4 Design-specific review standard*

The NRC reviewed Gap Analysis Report, based on the SRP, and developed a Design-Specific Review Standard (DSRS) tailored to the NuScale design. The DSRS provides review criteria specific to NuScale design [5].
The primary focus areas of the DSRS review include:

- *Analysis of outcomes resulting from a single component malfunction*
- *Evaluation of potential contamination on both the external and internal surfaces of the containment vessel and its impact on containment heat removal performance*
- *Proposed design provisions and plans for periodic in-service inspection and operability testing of systems and components*
- *Ultimate heat sink design review*
- *Assessment of long-term cooling capability loss due to debris generated by a LOCA*
- *Review of Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC)*

Due to NuScale integral design and multiple modules, the DSRS incorporates GDC 5. According to 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. In particular, the ability of remaining units to maintain safety functions including shutdown and cooling must remain unimpaired if a malfunction occurs in any single unit.

As a result of NuScale design of the containment heat removal system, active components such as spray systems are excluded from the DSRS review.

*3.5 Standard design certification application*

In December 2016, following the pre-application review process, NuScale Power submitted its Standard Design Certification application, with topical reports, a FSAR, which included exemption requests. NuScale requested 17 exemptions in total, one of which concerns GDC 40 in Appendix A to 10 CFR Part 50, related to testing of the containment heat removal system [6]. 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 [7].

*3.6 Final safety evaluation*

In June 2020, the NRC certified NuScale design and approved an exemption from GDC 40 for the containment heat removal system. As detailed in the FSER Section 6.2.2, the NRC found that this system meets all applicable regulatory requirements, maintains functionality under single-failure conditions, and can effectively manage debris and chemical byproducts generated during a LOCA [8]. NuScale applied Principal Design Criterion (PDC) 38 in lieu of GDC 38, achieving the same safety function. Whereas GDC 38 is grounded in the design principles of conventional light-water reactors, PDC 38 has been adapted to account for NuScale design, notably substituting a passive cooling approach for the active systems presumed under the traditional criterion the NRC approved that by complying with GDC 39, the containment heat removal system of NuScale can assure its operability without periodic performance testing as stipulated by GDC 40.

The FSER also reviewed how NuScale design addresses chemical interactions that could affect long-term cooling. To mitigate potential corrosion or chemical precipitates, NuScale excludes certain materials and pH buffering agents from the containment environment. The NRC determined these design choices help ensure sustained heat removal capability and protect nuclear fuel cladding integrity. Consequently, the Commission concluded that NuScale design meets 10 CFR 50.46(b)(5), PDC 38, and GDC 39 under LOCA conditions involving debris and chemical effects, and that its request for exemption from GDC 40 is justified.

## 4. Domestic Regulatory case

*4.1 Regulatory cases of SMART100*

SMART100 (Small Modular Advanced Reactor Technology 100), developed by the Korea Atomic Energy Research Institute (KAERI), is a 100 MWe integral pressurized water reactor that consolidates key components (steam generator, pressurizer, reactor coolant pumps) within the reactor vessel to enhance safety and allow for various applications.

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. The CAP code analyses show that the designed containment pressure exceeds predicted maximum pressure by at least 10%, but the pressure does not drop below 50% of its peak value within 24 hours.

Regulatory authorities require proof that SMART100 containment meets Article 23(1)(1) of the Regulations on Technical Standards for Nuclear Reactor Facilities, Etc and that conservative LOCA dose assessments remain under 10 CFR 100.11 limits. Beyond meeting the functional acceptance criteria (Regulatory Standard 7.2.3.1), the focus lies on preventing radioactive releases outside containment.

Since the CPRSS differs significantly from active systems, further design verification was needed, particularly regarding pressure reduction performance, dose assessments, and containment integrity. Establishing inspection and testing programs tailored to passive system characteristics is crucial for regulatory approval [9].

The licensing results confirmed that during a DBA, the maximum pressures in the upper and lower regions of the containment building have safety margins of 22.6% and 28.4% compared to the design pressure, ensuring structural integrity. Additionally, the containment building pressure increase was effectively suppressed for the first 72 hours after the accident, followed by a gradual pressure reduction beyond 72 hours. After initiating shutdown cooling in the reactor coolant system, long-term cooling operations successfully restored the containment building pressure to its initial level. A conservative dose assessment confirmed that radiation levels at the site boundary remained within the limits specified by 10 CFR 100.11.

Ultimately, since the containment barrier function was maintained to minimize radioactive material release, the requirements of Article 23 of the Regulations on Technical Standards for Nuclear Reactor Facilities, Etc (Containment Building, etc.) were satisfied [10].

### *4.2 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 KINS Safety Review Guidelines for LWRs, Section 6.2.2. Both GDC 38 and Article 23 of the Regulations on Technical Standards for Nuclear Reactor Facilities, Etc. require that the containment heat removal system rapidly reduce containment pressure and temperature following DBA. Article 41 of the Regulations on Technical Standards for Nuclear Reactor Facilities, Etc., which emphasizes periodic inspections and tests of components, parallels GDC 39 and 40. It was also confirmed that the requirement in 10 CFR 50.46(b)(5) for ensuring long-term cooling is similar to that of Article 24 of the Regulations on Technical Standards for Nuclear Reactor Facilities, Etc. [11].

Under Article 41 of the Regulations on Technical Standards for Nuclear Reactor Facilities, Etc., regular testing is intended to verify the performance of active components. However, in 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 [12]. Because these passive loops are continuously open, it is not feasible to conduct in-service tests to verify functionality in the same manner as active systems, potentially creating a regulatory gap.

Consequently, there is a need to analyze how NuScale, which has similarly adopted a passive containment heat removal system in its i-SMR design, addressed the requirements of GDC 40 and how the regulatory authority evaluated this approach.

## 5. Conclusion

Main purpose of current containment heat removal requirements is to quickly lower and sustain containment pressure and temperature during DBA, thus preserving safety functions. In NuScale PCCS licensing, a regulatory gap emerged regarding periodic performance tests deemed impractical for passive systems reliant on neither power nor pumps leading the NRC to grant an exemption under 10 CFR 50.12. Moving forward, similar challenges are expected for i-SMR, underscoring the need to clarify exemption criteria and procedures.

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