

Review of Regulatory Issues on Passive Containment Heat Removal System

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1. Introduction

Passive safety systems are now used in nuclear power plants, and the containment heat removal (CHR) function has also changed from active to passive. The Economic Simplified Boiling Water Reactor (ESBWR) and the AP1000 have a dedicated safety-related passive containment cooling system. It is called PCCS in the ESBWR and PCS in the AP1000. The NuScale design has no dedicated system. Instead, CHR is a function of the steel containment vessel (CNV), which is immersed in a reactor pool. In conventional plants this function is done by active systems such as containment sprays or fan coolers.

The regulatory requirements for CHR, however, were written for active systems. The U.S. NRC states this directly in its review of the NuScale design: *"The testing requirements were written for large containments with active cooling systems, such as containment sprays, rather than passive conduction and convection-driven heat transfer mechanisms"* [5]. A passive design therefore changes not only the equipment, but also what the regulator can verify, and how the requirement has to be read.

This paper reviews the design and the U.S. licensing records of the CHR systems (or functions) of the ESBWR, AP1000, and NuScale designs. The regulatory

issues that appear when CHR is made passive are then derived. The design control documents (DCD) or final safety analysis reports (FSAR), the NRC final safety evaluation reports (FSER), and the related requests for additional information (RAI) were used as primary sources [2-8].

2. Requirements for Containment Heat Removal System

Table 1 shows the requirements that apply to CHR from the regulatory review point of view. The ESBWR and the AP1000 use the general design criteria (GDC) of 10 CFR Part 50 Appendix A directly. NuScale is an integral PWR and uses principal design criteria (PDC), which are adapted from the GDC, but keep the same numbers. The main requirements are GDC 38 for performance, GDC 39 for inspection and GDC 40 for testing. GDC 55, 56, and 57 for containment isolation are also important here, because a passive CHR loop can cross the containment boundary. 10 CFR 50.46(b)(5) covers long-term cooling, and 10 CFR 50.44 covers combustible gas control. For a first-of-a-kind passive design, 10 CFR 52.47(b)(2)(i) is important because the performance has to be shown by a test program and not by plant operation.

Table I: Regulatory requirements applied to containment heat removal

Requirement	Title	Key content	Underlying purpose
GDC 38	Containment Heat Removal	Reduce rapidly and keep containment pressure and temperature at acceptably low levels after any LOCA, assuming a single failure	Prevent containment overpressure failure and keep the fission-product barrier
GDC 39	Inspection of CHR System	Permit periodic inspection of components	Confirm integrity over plant life
GDC 40	Testing of CHR System	Periodic testing of leak-tight integrity, of active components, and of the whole system	Show periodically that the system can work on demand
GDC 55, 56, 57	Containment isolation	Isolation valves on lines that penetrate the containment; GDC 57 covers lines neither in the RCPB nor open to the containment atmosphere	Keep a barrier against release of radioactive material
10 CFR 50.46(b)(5)	Long-Term Cooling	Keep core temperature low and remove decay heat for the extended period required	Assure long-term core and containment heat removal
10 CFR 50.44	Combustible Gas Control	Control generation and accumulation of hydrogen in containment	Prevent a hydrogen combustion threat to containment
10 CFR 52.47(b)(2)(i)	Test program	Performance of a first-of-a-kind design shall be shown by an analysis, test or experience program	Verify passive performance not testable in the plant

3. Containment Heat Removal in Advanced LWRs

3.1 ESBWR PCCS

Six condenser loops are placed in the IC/PCCS pool above the drywell, and this pool is vented to the atmosphere. The steam-gas mixture enters the tubes because of the pressure difference between the drywell and the wetwell, and it condenses there. The condensate drains by gravity to the GDCS pools and returns to the vessel. The noncondensable gases are discharged below the surface of the suppression pool. Each loop removes at least 7.8 MWt of latent heat [2]. The NRC records that the condensers are treated as "an extension of the safety-related containment drywell pressure boundary and thus not needing isolation valves" [2]. The containment pressure stays below the design pressure of 310 kPaG for 72 hours, with no active system, electric power, or operator action.

3.2 AP1000 PCS

Steam condenses on the inside of the steel containment vessel. The heat is then removed "via conduction through the steel containment vessel, convection from the containment surface to the water

film, convection and evaporation from the water film to the air, and radiation from the water film to the air baffle" [4], while air circulates naturally in the annulus between the vessel and the shield building. Water is supplied by gravity from an 800,000 gal. passive containment cooling water storage tank (PCCWST) through three parallel flow paths, and only one path is needed for minimum containment cooling [4]. For the limiting double-ended cold-leg guillotine (DECLG) LOCA, the peak pressure is 58.1 psig and the design pressure is 59 psig, so the available margin is 0.9 psi [4].

3.3 NuScale CHR Function

The small and high-pressure CNV of each power module is immersed in the reactor pool and is normally evacuated. When the ECCS valves open, the steam that enters the CNV condenses on the inner wall. The heat is conducted through the wall to the pool, which is the ultimate heat sink. There is no spray, no fan cooler, and no dedicated CHR system. For US600, the peak containment pressure is 994 psia against a design pressure of 1050 psia, which is about 5% margin [5]. For US460, it is 919 psia against 1200 psia, and the staff records "an about 22 percent pressure safety margin", which meets the 10% guidance [7].

Table II: Comparison of containment heat removal in the three designs

Item	ESBWR PCCS	AP1000 PCS	NuScale (CNV function)
Containment type	Pressure suppression	Steel large dry	Pool-immersed small CNV
Heat removal mechanism	In-tube condensation in submerged condenser	Shell-outside water film evaporation + air	Inner-wall condensation, wall conduction to pool
Ultimate heat sink	IC/PCCS pool to atmosphere	PCCWST water + air to atmosphere	Reactor pool to atmosphere
Active component	None (vent fans after 72 h)	PCCWST isolation valves, no pump	None dedicated (ECCS valves)
Design / peak pressure	310 kPaG design, below design for 72 h	59 psig / 58.1 psig (0.9 psi)	1050/994 psia (US600), 1200/919 psia (US460)
Performance demonstration	PANTHERS, PANDA, GIRAFFE + TRACG	Surrogate flow and coverage test + WGO THIC	NIST-1/-2 + NRELAP5, GDC 40 exempted

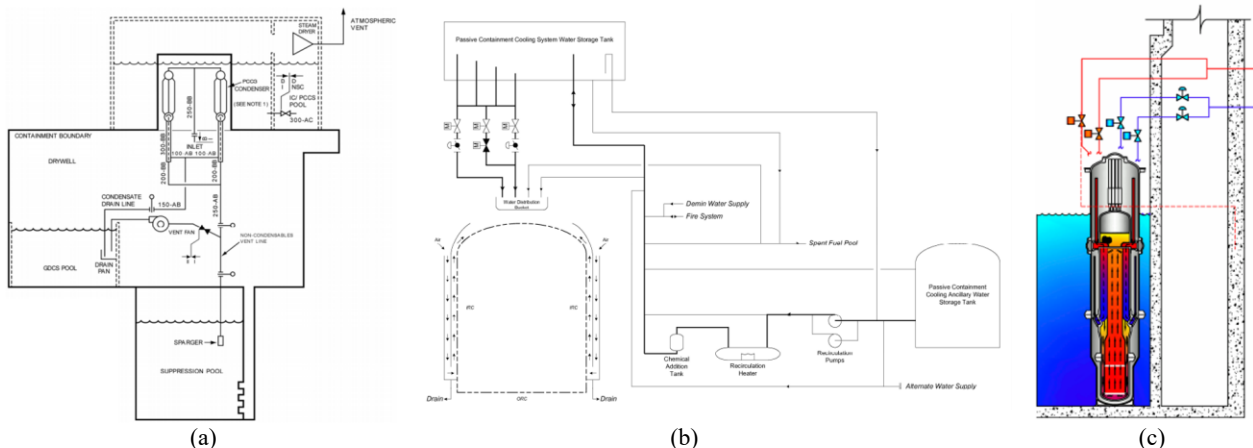


Fig. 1. Containment heat removal configurations: (a) ESBWR PCCS [3], (b) AP1000 PCS [4], and (c) NuScale power module immersed in the reactor pool [8].

4. Regulatory Issues on Passive Containment Heat Removal

4.1 Re-interpretation of GDC 38

The AP1000 meets GDC 38 against a conventional quantitative criterion. Its DCD gives an acceptance value of " < 29.5 psig", which is one half of the design pressure, and reports " < 27 psig after 24 hrs" for the DECLG LOCA [4]. The ESBWR could not do this. TRACG predicts that the containment pressure *"is still rising at 72 hours"*. The NRC therefore found that *"the PCCS does not appear to rapidly reduce containment pressure and temperature"* and issued RAI 6.2-139 [2]. After the applicant added a passive autocatalytic recombiner system and PCCS vent fans, the staff concluded that the ESBWR *"does not reduce the containment pressure to as low a level as operating BWRs, but ... does provide adequate containment heat removal and meets the intent of GDC 38"* [2]. The staff also added that *"the staff interpretation of GDC 38 applies specifically to the ESBWR passive design but, potentially, also to other similar passive safety systems"* [2]. This is an explicit precedent for future passive designs.

Table II: Comparison of containment heat removal in the three designs

Design	Regulatory issue	Basis	Disposition
ESBWR	Pressure still rising at 72 h; not rapidly reduced	GDC 38	PARS and vent fans added; intent of GDC 38 met (RAI 6.2-139)
ESBWR	PCCS has no containment isolation valves	GDC 55/56	Accepted as part of the containment, not a penetration (RAI 6.2-102)
ESBWR	H ₂ /O ₂ detonation in valve-less closed loop	10 CFR 50.44	Material/thickness change; function kept after repeated detonations (RAI 6.2-202)
AP1000	Available margin of only 0.9 psi (1.5 %) at DECLG	GDC 38	Accepted; GDC 38 24-h criterion met (< 27 psig)
AP1000	Heat removal rate not directly tested	GDC 40	Surrogate flow and coverage test, analysis-based alternative
NuScale	CHR performance cannot be tested	GDC 40	Exemption; no ITAAC and no performance surveillance
NuScale	72-h claim from 12.5-h calculation	10 CFR 50.46(b)(5)	Accepted as a benign decay-heat-governed transient
NuScale	Condensation correlation reused at +56 % power	GDC 38	Applicability extended; phenomena unchanged

4.3 Containment isolation (GDC 55, 56, and 57)

These criteria require isolation valves on lines that penetrate the containment. A passive CHR loop does not fit this model because closing the valves would also stop the heat removal. The ESBWR PCCS has no containment isolation valves (CIVs) at all. The applicant argued that the condensers are part of the containment itself, not a penetration. The staff accepted this and wrote that the PCCS *"provides a functional feature of the ESBWR primary containment"* and *"is not a separate fluid process system"* [2]. The staff's own risk calculation found that *"the proposed PCCS design without isolation valves represents lower risk than the*

4.2 A spectrum of testability under GDC 40

None of the three designs can measure its containment heat removal rate in the plant, and each one uses a different substitute. The ESBWR used a scaled test program with the PANTHERS, PANDA and GIRAFFE facilities. The NRC audited them, and the data were used to qualify TRACG [2]. The AP1000 uses a surrogate test. A periodic flow test shows a minimum flow rate of 469.1 GPM and confirms water coverage by visual inspection. An alternative is also allowed, namely that *"a report exists and concludes that the as-measured flow rates ... provide sufficient heat removal capability"* [4]. NuScale received an exemption from GDC 40 under 10 CFR 50.12, based on undue hardship. The condensation inside the CNV is *"impractical to test after the fuel is loaded using the as-built configuration"*, and the through-wall conduction and pool convection are *"difficult to measure empirically"* [5]. As a result, *"there are no ITAAC associated with the containment heat removal function of the CNV"* [5, 7], and the technical specifications monitor only surrogates such as pool inventory and temperature.

alternative design with isolation valves" [2]. GDC 57 appeared in a different way. It allows one valve outside containment when a closed system inside containment works as the second barrier. The staff noted that *"no ESBWR system credits a closed system inside containment (per GDC 57) as a containment isolation barrier"* [2], and the applicant corrected the affected tables to cite GDC 56.

4.4 Design-specific issues

In the ESBWR, radiolytic hydrogen and oxygen accumulate in the valve-less closed loop and may *"reach concentration levels that supports detonation"*.

RAI 6.2-202 was resolved by a material change and a thickness increase, so that the PCCS is *"able to perform its safety function after undergoing multiple hydrogen detonations"* [2]. In the AP1000, the pressure margin of 1.5% leaves little room for re-analysis. In NuScale, the long-term cooling transient was computed with *"NRELAP5 only out to 12.5 hours ... and a state point method is used to infer the NPM conditions at 72 hours"*. The staff acknowledged that *"the results may be dominated by numerical noise"* [6]. The power of the NPM-20 also increased, but the staff still accepted *"extending the applicability and usage of the condensation correlation approved for NPM-160 to the NPM-20 design"*, because the PIRT ranking and the phenomena did not change [7].

5. Conclusions

The three designs made containment heat removal passive by using three different ultimate heat sinks. All three met the same kind of regulatory difficulty. First, requirements that were written for active systems had to be re-read. GDC 38 was met in intent and not in letter for the ESBWR. GDC 40 was met by a surrogate test in the AP1000 and was waived by exemption in NuScale. Containment isolation was handled by treating the PCCS as a part of the containment in the ESBWR. Second, the performance cannot be demonstrated in the plant, so the verification depends on scaled test facilities and qualified computer codes. The adequacy of the scaling and of the code applicability then becomes the main licensing question. Third, a passive design brings issues that active designs did not have, such as the accumulation of detonable gas in a valve-less closed loop. An applicant who adopts passive containment heat removal should therefore prepare two things from the early design stage. One is an argument on the underlying purpose of each requirement. The other is a performance demonstration strategy that combines scaled testing with code qualification.

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REFERENCES

- [1] 10 CFR Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants," GDC 38, 39, 40, 55, 56 and 57.
- [2] U.S. NRC, FSER for the ESBWR Standard Design, NUREG-1966, Vol. 2, Sections 6.2.2 and 6.2.4, 2014.
- [3] GE-Hitachi Nuclear Energy, ESBWR Design Control Document, Tier 2, Ch. 6, Rev. 10, 2014.

- [4] Westinghouse Electric Company, AP1000 Design Control Document, Tier 2, Ch. 6 and 16, Rev. 20, ML26086A412, 2026.
- [5] U.S. NRC, FSER, NuScale Standard Design Certification, Ch. 6, ML20205L406, 2020.
- [6] U.S. NRC, FSER, NuScale Standard Design Certification, Ch. 15, ML20205L408, 2020.
- [7] U.S. NRC, FSER, NuScale US460 Standard Design Approval, Ch. 6, Rev. 2, ML25085A431, 2025.
- [8] NuScale Power, NuScale US460 SDAA, Final Safety Analysis Report, Ch. 1, Rev. 2, ML25099A239, 2025.