

Toward an Integrated Risk-Informed and Performance-Based Safety Classification Model for Small Modular Reactor Systems

Manwoong Kim,^{1,2*} Sukho Lee¹

Nuclear Safety International, 62 Gwahak-ro, Yuseong-gu, Daejeon 34142. Republic of KOREA

Pohang University of Science and Technology, 77 Cheongam-ro, Pohang-si 37673. Republic of KOREA

*Corresponding author: drmwkim@postech.ac.kr

**Keywords : Small Modular Reactor (SMR), Safety Classification, Risk-Informed, Performance-Based, Probabilistic Safety Assessment (PSA), Nuclear Safety, Reliability Target, Design Criteria.*

1. Introduction

Safety classification of structures, systems, and components (SSCs) is a cornerstone of nuclear reactor design and regulatory oversight. Traditionally, SSCs have been classified within a deterministic defense-in-depth framework, in which safety functions are defined by their roles in mitigating postulated initiating events and preventing unacceptable radiological consequences. This approach has provided regulatory clarity and demonstrated robustness for large light-water reactors (LWRs), where clearly defined engineered safety systems are explicitly credited in licensing-basis accident analyses.

However, the deterministic paradigm—whereby structures, systems, and components (SSCs) that perform safety functions and are credited in safety analyses are classified as safety-related—remains valid for advanced reactor technologies, including Small Modular Reactors (SMRs). The main limitation arises not from the paradigm itself, but from the application of prescriptive methodologies originally developed for conventional large reactors without sufficient consideration of SMR-specific characteristics (e.g., predefined shutdown temperatures such as 215°C which is the reference temperature set for automatically reactor shut-down if the coolant temperature reaches 215°C

SMRs incorporate passive safety systems based on inherent features such as natural circulation, gravity-driven injection, and passive heat removal, and in most designs these systems are explicitly credited in safety analyses and classified accordingly. Systems that are not credited such as Regulatory Treatment of Non-Safety Systems (RTNSS), are categorized as non-safety-related and are typically designed as active systems. Extending passive design principles to non-safety-related systems may constitute overdesign and may not achieve the same level of performance efficiency as active designs. While there are limited exceptions, such as the use of stored-energy systems (e.g., batteries) in certain designs like NuScale, these are considered design-specific rather than representative of general practice.

Nevertheless, probabilistic safety assessments (PSAs) often show that these systems play a dominant role in

reducing core damage frequency (CDF) and large release frequency (LRF).

This disconnect between formal safety classification and actual risk significance creates two opposing inefficiencies. Risk-significant SSCs may receive insufficient regulatory attention if classified as non-safety-related, while SSCs with limited risk contribution may be subject to unnecessarily stringent design codes, quality assurance measures, and inspection requirements due solely to deterministic criteria. Consequently, the regulatory structure may become economically inefficient and misaligned with true safety priorities.

To address these challenges, risk-informed regulatory initiatives—such as Risk-Informed Safety Classification (RISC), the Regulatory Treatment of Non-Safety Systems (RTNSS), and Reliability Assurance Programs (RAP) which have been introduced. Although these tools represent meaningful progress, they are typically implemented as supplements to the existing deterministic framework rather than as components of a fully integrated, performance-oriented system. As a result, risk insights are often not directly translated into explicit and quantitative regulatory requirements.

This study proposes a unified risk-informed, performance-based (RI-PB) safety classification framework tailored to Small Modular Reactors (SMRs). Unlike conventional risk-informed approaches that primarily re-categorize SSCs within predefined safety classes, the proposed framework shifts the focus from classification labels to quantitative performance expectations. It explicitly assigns numerical reliability targets to safety functions based on both deterministic consequence considerations and probabilistic risk contributions. These targets are then used to guide the selection of design codes, inspection scope, testing frequency, and quality assurance requirements, thereby establishing a transparent and auditable linkage between risk insights and engineering implementation.

By integrating safety significance, probabilistic risk contribution, and quantitative reliability criteria into a coherent methodology, the proposed framework aims to enable a more proportionate, transparent, and technically justified application of regulatory

requirements. In doing so, it seeks to enhance both safety and regulatory efficiency in the design and licensing of advanced SMRs.

2. Limitation of Traditional Safety Classification for SMRs

2.1. Deterministic Safety Classification

Deterministic safety classification assigns structures, systems, and components (SSCs) to predefined safety classes according to their credited roles in fulfilling fundamental safety functions, namely reactivity control, core heat removal, and confinement of radioactive materials under postulated initiating events. In this framework, the significance of an SSC is primarily determined by the potential radiological consequences associated with the failure of its safety function. These consequences are typically evaluated against dose limits and acceptance criteria established by national regulations and international standards, including those developed by the International Atomic Energy Agency. This approach has historically provided regulatory clarity, consistency, and a conservative basis for ensuring nuclear safety.

However, when applied to Small Modular Reactors (SMRs), the deterministic approach exhibits important limitations. First, it does not explicitly account for the frequency of initiating events or the relative contribution of individual SSCs to overall plant risk, thereby limiting its ability to distinguish between high- and low-risk contributors in a quantitative manner. Second, although often central to SMR safety strategies passive systems and inherent safety features may not receive formal safety credit if they are not explicitly relied upon in licensing-basis accident analyses. As a result, their regulatory treatment may not always fully reflect their actual risk significance. In most SMR designs, passive systems are explicitly credited in safety analyses and are appropriately classified within the existing deterministic framework. However, certain design features may still present challenges in consistently capturing their relative importance. In addition, key characteristics of SMRs such as reduced source terms and the availability of diverse or alternative success paths, are not always fully represented within a purely consequence-based classification scheme. Together, these considerations suggest the need for a more integrated framework that complements deterministic principles with explicit incorporation of probabilistic risk insights, while remaining consistent with current practices of crediting passive safety systems.



2.2. Risk-Informed Safety Classification (RISC)

Risk-Informed Safety Classification (RISC) enhances traditional deterministic classification by incorporating insights from probabilistic safety assessment (PSA). Under this approach, SSCs are categorized not only according to their conventional

safety-related designation but also based on their quantitative contribution to overall plant risk. By combining deterministic safety functions with probabilistic risk significance, RISC seeks to achieve a more balanced and risk-informed allocation of regulatory attention.

This concept is formalized in 10 CFR 50.69, issued by the U.S. Nuclear Regulatory Commission in 1995, which establishes alternative treatment requirements for SSCs based on their risk-informed categorization. Within this framework, SSCs are grouped into four categories that reflect both their safety-related status and their relative risk importance, as shown in Table 1.

Table 1 10CFR50.69 RISC Categories

Risk-informed 	1 "RISC-1" SSCs Safety-Related Safety-Significant	2 "RISC-2" SSCs Nonsafety-Related Safety-Significant
	3 "RISC-3" SSCs Safety-Related Low-Safety-Significant	4 "RISC-4" SSCs Nonsafety-Related Low-Safety-Significant
	 Deterministic	

RISC-1 includes SSCs that are safety-related and also determined to be highly significant to plant safety. These components remain subject to the most stringent regulatory oversight and special treatment requirements, consistent with their critical role in preventing or mitigating accidents.

RISC-2 comprises SSCs that are not traditionally classified as safety-related but are identified through PSA as significant contributors to plant safety. This category is particularly relevant for SMRs, where passive systems, inherent safety features may play a dominant role in risk reduction. However, it should be noted that the classification framework proposed in this paper aligns with the risk-informed categorization; under 10 CFR 50.69, where such systems would be classified as safety-related. This differs from conventional design practices in which passive systems are often designated as non-safety-related. To avoid potential confusion, an alternative terminology that reflects the risk-informed safety significance—rather than the traditional safety classification—may be considered.

RISC-2 ensures that such components receive appropriate regulatory treatment commensurate with their actual safety importance.

RISC-3 includes SSCs that are safety-related under deterministic criteria but are shown through PSA to have low safety significance. This categorization permits a graded reduction in special treatment requirements, thereby alleviating unnecessary regulatory burden without compromising overall

safety. For example, certain components in this category may be procured using commercial-grade items rather than more costly nuclear-grade equipment, provided that performance requirements are

$$RAW = \frac{\text{Total risk assuming the SSC is failed}}{\text{Base-case total risk}}$$

maintained.

Finally, RISC-4 encompasses SSCs that are neither safety-related nor risk-significant. These components continue to receive minimal regulatory oversight consistent with their limited impact on plant risk.

Overall, the RISC framework represents an important step toward integrating probabilistic insights into regulatory decision-making by aligning the level of oversight more closely with actual risk significance.

3. Proposed Risk-Informed and Performance-Based Framework

3.1. Conceptual Basis

The proposed RI-PB framework departs from prescriptive, class-based requirements and instead focuses on safety functions and their required performance. SSC classification is derived from the combination of:

- Deterministic consequence severity of safety function failure, and
- Probabilistic risk significance, quantified using PSA importance measures.

This combination enables the assignment of explicit, quantitative reliability targets that are directly traceable to plant-level safety goals.

3.2. Framework Structure

The framework consists of four core elements:

(1) Safety Function Identification\

All safety functions are identified and grouped into reactivity control, core heat removal, and radioactive material confinement. Design-specific passive functions are explicitly included.

(2) Deterministic Consequence Safety Categorization

The consequences of failure to perform each safety function are categorized as:

- Category 1 (High): Potential for core damage or large early release
- Category 2 (Medium): Fuel damage or limited release
- Category 3 (Low): Minimal impact on public safety

(3) Risk Significance-based Categorization

PSA Level 1 and Level 2 models are used to evaluate the importance of SSCs using:

- Fussell-Vesely (FV) importance

$$FV = \frac{\text{Risk from sequences involving the SSC}}{\text{Total plant risk}}$$

- Risk Achievement Worth (RAW)

The criteria for classifying a component as high risk-informed safety significance (RISC-1), intermediate risk-informed safety significance (RISC-2), or low risk-informed safety significance (RISC-3) are based on Probabilistic Safety Assessment (PSA) metrics. Although FV and RAW are standard PSA importance measures, their numerical thresholds vary depending on regulatory context and programmatic objectives. Key criteria from various sources are summarized below:

- ASME Code Case: Classifies a component as an RISC-1 if its FV > 0.005 or its RAW > 2.
- PSA Application Guide: Has more detailed criteria for both systems and components. For components, an RISC-1 has an RRW > 1.005, FV > 0.005, or RAW > 2.
- NUMARC 93-05: Uses FV to define high, medium, and low significance for Motor-Operated Valves (MOVs), with FV > 0.01 being the threshold for high significance (RISC-1).
- EPRI Pilot Project: Uses both FV and RAW to classify components into high, medium, and low categories. For example, a high-significance component(RISC-1) has an FV > 0.01 or RAW > 10.
- NUMARC 93-01: Classifies a component as high risk-informed significant (RISC-1) if its RRW > 1.005, RAW > 2, or if it cumulatively accounts for about 90% of the total CDF.
- BWR Owners Group: Categorizes components based on the percentage of CDF they contribute, with >1% of CDF being the threshold for a high-significance component (RISC-1).
- WOG Periodic Verification of MOV: Provides two different classification methods, both using combinations of FV and RAW to define HSSCs.
- South Texas: Defines RISC-1 as having an FV (for either CDF or LERF) > 0.005.

These variations demonstrate that while PSA importance metrics are standardized, their application and threshold selection are tailored to specific regulatory programs, plant types, and technical objectives, such as risk-informed in-service testing or Maintenance Rule implementation.

(4) Performance-based Categorization

Based on consequence category and PSA importance, SSCs are assigned to one of the reliability target-based classes as follows:

- SC-1 (High Reliability): $R \geq 0.9999$ per demand
- SC-2 (Medium Reliability): $0.999 \leq R < 0.9999$ pRer demand
- SC-3 (Basic Reliability): $0.99 \leq R < 0.999$ per demand
- Non-Safety: No reliability target

These reliability targets provide a direct basis for selecting design codes, inspection intervals, and quality assurance levels, as shown in an example classification criteria matrix of Table 2.

An SSC can be assigned a lower class than traditional deterministic methods if PSA demonstrates its low risk significance, provided the assigned reliability target is demonstrably achievable through its design, manufacturing, and operational controls.

In this study, the reliability targets are derived from plant-level safety objectives, such as core damage frequency and large release frequency goals, and are consistent with reliability levels implicitly assumed in current nuclear design and regulatory practice.

For example, a target reliability of 0.9999 per demand for SC-1 functions corresponds to failure probabilities already embedded in single-failure criteria, redundancy requirements, and surveillance testing intervals applied to traditional safety-related systems.

The proposed framework makes these implicit expectations explicit and traceable, rather than introducing new or more stringent requirements.

4. Integrated Safety Framework for SMRs

4.1. Safety Characteristics of SMRs

SMRs incorporate extensive passive safety features—such as natural circulation, gravity-driven injection, and passive heat removal—and in most designs these systems are explicitly credited in deterministic safety analyses and classified as safety-related SSCs. Consequently, the overall reliance on traditionally safety-related active systems is reduced.

For example, in many SMR designs, decay heat removal is achieved through passive heat removal systems that rely on natural circulation and heat conduction to ultimate heat sinks, and these systems are directly credited in safety analyses as safety-related functions. In contrast, systems such as the RTNSS are not credited in safety analyses, are classified as non-safety-related, and are typically designed as active systems.

Similarly, certain support systems such as normal feedwater systems or turbine-related systems, may contribute to transient mitigation or operational stability but are not credited for accident mitigation in deterministic analyses and are therefore classified as non-safety-related. These examples illustrate that, while SMRs rely heavily on passive safety features for core safety functions, non-safety-related systems remain predominantly active and are not assigned primary safety roles within the deterministic framework.

For example, in the NuScale design, key safety functions such as emergency core cooling and decay heat removal are performed by passive systems that are explicitly credited in safety analyses (NuScale FSAR, Chapters 6 and 15). In contrast, although

capable of initiating reactor trip, the RTNSS, is not credited in accident analyses and is therefore classified as a non-safety-related active system (NuScale FSAR, Chapter 7). Similar approaches are adopted in other SMR designs, such as Westinghouse SMR and SMART, where passive safety systems are credited for design-basis accident mitigation.

Another illustrative case is the use of batteries for reactor trip and decay heat removal functions in certain advanced SMR designs. In some instances, these batteries are classified as non-safety-related under the traditional deterministic framework because they are not included in the licensing basis analyses, yet probabilistic safety assessments (PSAs) indicate that they contribute significantly to the reduction of core damage frequency (CDF) and large release frequency (LRF) for NuScale Power, LLC

These examples highlight the disconnect between deterministic safety classification and actual risk significance in SMRs, demonstrating the need for a more integrated, risk-informed classification framework that captures the true importance of components beyond traditional deterministic credit and ensures that all risk-significant SSCs receive appropriate attention regardless of their conventional safety classification.

4.2. Integrated Application of RISC, RTNSS, and RAP

A robust safety framework for SMRs requires the integrated application of three complementary approaches:

(1) Risk-Informed Safety Classification (RISC)

RISC uses PSA importance measures such as FV and RAW to classify SSCs according to their actual risk contribution. It enables:

- Reclassification of low-risk SSCs historically labeled as safety-related.
- Identification of high-risk SSCs that are not traditionally safety-related.

This approach enhances resource allocation efficiency while maintaining or improving overall plant safety.

(2) Regulatory Treatment of Non-Safety Systems (RTNSS)

The RTNSS is designed to provide regulatory oversight and quality assurance for non-safety-related but risk-significant SSCs, ensuring that their design and operation remain fully independent from safety-related systems so that any failure does not compromise the functionality or reliability of safety-related SSCs. For example, in the NuScale SMR design, RTNSS components have completely separated electrical and instrumentation pathways and do not interface with or override safety functions (NuScale FSAR, Chapter 7). This structured regulatory treatment ensures that risk-significant SSCs

receive appropriate oversight while preserving the integrity and independence of safety-related systems, which is a fundamental principle in the selection and regulation of RTNSS components.

(3) Reliability Assurance Program (RAP)

The Reliability Assurance Program ensures that all risk-significant SSCs maintain high reliability throughout their lifecycle, from design through operation and maintenance. In SMRs, safety-related SSCs, including passive safety systems credited in deterministic safety analyses, are designed with sufficient redundancy to accommodate single-fault conditions, while non-safety but risk-significant SSCs—such as the Reactor Trip Non-Safety System (RTNSS) or systems subject to regulatory commitments—are designed with appropriate multiplicity and are subject to regulatory oversight and quality assurance. RTNSS components remain fully independent from safety-related systems, so that any failure does not compromise safety functions (NuScale FSAR, Chapter 7). Together, these measures ensure that both safety-related and risk-significant non-safety systems achieve the reliability necessary for safe and compliant operation while preserving the integrity and independence of safety functions.

4.3. Classification of Passive Equipment in SMRs

The integration of Risk-Informed Safety Classification (RISC), Regulatory Treatment of Non-Safety System (RTNSS), and Reliability Assurance Program (RAP) provides a systematic and risk-informed framework for classifying passive equipment in SMRs. In contrast to traditional deterministic approaches based primarily on design-basis accident criteria, this methodology incorporates PSA results to quantify the risk contribution of individual components. Safety or non-safety grades are therefore assigned according to objective risk metrics, rather than solely on prescriptive design classifications as shown in Table 3, the practical implementation of this approach results in a revised component classification scheme.

Within this framework, PSA serves as the primary basis for determining component safety significance. Equipment with measurable contributions to core damage frequency (CDF), large early release frequency (LERF), or related plant-level risk metrics is classified in proportion to its quantified impact, irrespective of its conventional deterministic designation. This ensures that reliability, availability, and performance requirements are commensurate with actual risk importance.

As illustrated in Table 4, the practical implementation of this approach results in a revised component classification scheme that directly links risk significance and the reliability targets to regulatory and operational controls, including surveillance, maintenance, quality assurance, and performance monitoring. By aligning equipment grading with

quantified risk insights, the framework strengthens consistency between safety analysis and operational management.

Although non-safety but risk-significant SSCs may not be classified as safety-related under deterministic frameworks, their failure can meaningfully influence overall plant risk. Passive safety systems, in contrast, are explicitly recognized as safety-related due to their core safety functions. The integrated RISC–RTNSS–RAP methodology addresses this by systematically identifying and managing risk-significant and non-safety-class SSCs, ensuring that both safety-related and operationally important non-safety systems achieve the reliability necessary to support safe and compliant SMR operation while preserving the independence and integrity of safety functions.

Overall, the harmonization of deterministic design principles with probabilistic risk insights establishes a balanced, performance-based safety management framework. For SMRs, this ensures that reliability and availability targets are maintained in accordance with true risk significance, while supporting efficient resource allocation and preserving the economic advantages of simplified reactor designs.

5. Case Study: Application to an Integral LWR SMR

To demonstrate the practical implementation of the Risk-Informed, Performance-Based (RI-PB) framework, a hypothetical 100 MWe integral light water reactor (LWR) small modular reactor (SMR) is considered. The case study focuses on the classification and management of the passive decay heat removal system (PDHRS) within the integrated safety classification framework.

The PDHRS performs a high-consequence safety function and is therefore categorized as Function Category A. However, Probabilistic Safety Assessment (PSA) results indicate only moderate risk importance, primarily due to the presence of alternative success paths and the inherently low failure probability of the passive design. Based on the quantified risk contribution presented in Table 5, a reliability target of 0.999 per demand is established to ensure consistency with plant-level risk objectives.

Applying the integrated safety classification criteria for SMRs (Table 4), the PDHRS is assigned Safety Class 2 (SC-2 and RISC-2). This classification reflects its safety function and risk contribution while avoiding automatic assignment to the highest deterministic safety class. Consequently, less restrictive design codes may be applied compared to those required under traditional deterministic classification, as summarized in Table 6. Importantly, this flexibility does not compromise safety, as the classification and associated requirements are directly linked to quantified risk insights.

Within the RI-PB framework, safety assurance is achieved not through uniform application of the most

conservative design standards, but through demonstration that reliability targets derived from plant-level risk goals are met and sustained throughout the component lifecycle. This includes verification through design qualification, surveillance, maintenance, and performance monitoring. The case study thus illustrates how risk-informed classification enables balanced regulatory control, ensuring that safety objectives are satisfied while preserving the design and economic advantages of integral SMR concepts.

5. Conclusions

In conclusion, this study has demonstrated that conventional deterministic safety classification approaches are not fully aligned with the design philosophy and inherent safety characteristics of Small Modular Reactors (SMRs). To address this limitation, a Risk-Informed, Performance-Based (RI-PB) framework has been proposed that systematically integrates deterministic consequence analysis, probabilistic risk insights, and explicit performance objectives. This integrated approach provides a rational, transparent, and technically defensible basis for safety classification tailored to SMR designs.

By combining Risk-Informed Safety Classification (RISC), Risk-Targeted Non-Safety Systems (RTNSS), and Reliability Assurance Programs (RAP), the framework ensures that all risk-significant structures, systems, and components (SSCs)—irrespective of their traditional safety class—are subject to regulatory oversight commensurate with their actual contribution to plant safety. Application of the framework to a representative SMR design indicates that it can reduce unnecessary conservatism, optimize resource allocation, and enhance regulatory clarity, while maintaining—rather than compromising—the overall level of safety.

Importantly, the proposed RI-PB framework is fully compatible with existing regulatory processes. It builds upon established regulatory concepts already recognized and applied by authorities, including RISC, RTNSS, and reliability assurance programs. The principal contribution of this work lies not in introducing entirely new regulatory constructs but in providing a structured and coherent integration of these accepted elements into a unified classification methodology.

Accordingly, the framework can be implemented incrementally within current licensing practices, such as during pre-licensing design reviews or through topical reports for SMR applications. Future research should focus on sustained regulatory engagement, further refinement of SMR-specific PSA

methodologies, and the development of harmonized international guidance. With continued validation and practical demonstration, the RI-PB framework has the potential to support the safe, economical, and timely deployment of next-generation SMRs.

ACKNOWLEDGMENT

This study is supported by the Regulatory Research Management Agency for SMRs (RMAS) grant funded by the Nuclear Safety and Security Commission (NSSC)

REFERENCES

- [1] IAEA, SSG-30 Safety Classification of Structures, Systems and Components in Nuclear Power Plants (2014).
- [2] 10CFR50.69, Risk-Informed Categorization and Treatment of Structures, Systems and Components for Nuclear Power Reactors (2004)
- [3] NEI, Option 2 Implementation Guidelines, NEI 00-04 (2002).
- [4] KAERI, KAERI/TR- 2432/2003, A Study on Importance Measures for Risk Informed Regulation & Applications (2003)
- [5] ASME OMN-3 Code Case, Requirements for Safety Significance Categorization of Components Using Risk Insights for Inservice Testing of LWR Power Plants (1998)
- [6] EPRI/TR-105396 PSA Application Guide, (1995).
- [7] EPRI TR-105869 In-service Testing Pilot Project, (1995).
- [8] NUMARC 93-05, Guidelines for Optimizing Safety Benefits in Assuring the Performance of MOV (1993).
- [9] BOG, Application of PSA to Generic Letter 89-10 Implementation (1994). ASME. (2021). Boiler and Pressure Vessel Code, Section III, Division 5: High Temperature Reactors. The American Society of Mechanical Engineers.
- [10] U.S. Nuclear Regulatory Commission (NRC).. Regulatory Guide 1.201, Guidelines for Categorizing Structures, Systems, and Components in Nuclear Power Plants According to Their Safety Significance. (2021)
- [11] EPRI, Guidelines for Performance-Based, Risk-Informed Safety Classification for Non-LWR Advanced Reactors. EPRI Report 3002010404. (2018)
- [12] WOG, Risk Ranking Approach for MOVs in Response to Generic Letter 96-05 (1998) Idaho National Laboratory. (2022).
- [13] EPRI. (2021). Technical Basis for Risk-Informed Safety Classification of Advanced Reactor Systems. 3002020244. (2021)
- [14] Manwoong Kim, et. al., Perspective on the Classification Approaches for Passive and Non-Safety-Rated System and Components for SMRs, Transactions of the Korean Nuclear Society Autumn Meeting (2025)

Table 2. Combined SSC Classification Criteria Matrix by Reliability Target

Safety Class	Consequence Category	PSA Importance (e.g., FV > 0.001)	Target Reliability Range (Example)	Applicable Design Codes & QA
SC-1	1 (High)	High	$0.9999 \leq R$	Full ASME III Class 1 / Equivalent; Nuclear QA-1 (NQA-1)
SC-2	2 (Medium)	Medium to High	$0.999 - 0.9999$	ASME III Class 2 / 3; Nuclear QA-2 (Tailored NQA-1)
SC-3	3 (Low)	Low	$0.99 - 0.999$	ASME B31.1 / Industrial Standards; Rigorous Industrial QA
Non-Safety	Negligible	Not Risk Significant	No reliability target	General Industrial Standards

Table 3 Combined SSC Classification Criteria Matrix by Risk Significance

Classification	Safety Grade	QA Grade	RI-Based Risk-significant Criteria		Consequence Criteria	PB-Based Reliability Target
			RAW	FV	ΔCDF (1/year)	Failure Rate (FR)
1	RISC 1	1	$1.5 \leq RAW < 2.5$	$0.05 \leq FV < 0.12$	$1.0 \times 10^{-6} \leq \Delta CDF$	$FR \leq 1 \times 10^{-4}$
1-2	RISC 1,2	2	$1.0 \leq RAW < 1.5$	$0.01 \leq FV < 0.05$	$1.0 \times 10^{-7} \leq \Delta CDF < 1.0 \times 10^{-6}$	$1 \times 10^{-4} < FR \leq 1 \times 10^{-3}$
2	RISC 2	2	$RAW < 1.0$	$0 \leq FV < 0.01$	$1.0 \times 10^{-8} \leq \Delta CDF < 1.0 \times 10^{-7}$	$1 \times 10^{-3} < FR \leq 1 \times 10^{-2}$
3	RISC 3,	3	-	-	$\Delta CDF < 1.0 \times 10^{-8}$	$1 \times 10^{-2} < FR$
Non-Safety	NSG*	-	-	-	-	-

*NSG: Non-safety grade

- No reliability target or risk-significant criteria

Table 4. Integrated Safety Classification Criteria Framework for SMRs

Classification	PB-based Grade	RI-Safety Grade	QA Grade	Consequence Criteria	RI-Based Criteria		PB-Based Criteria	
				ΔCDF (1/year)	FV	RAW	Failure Rate (FR)	Reliability(R)
1	SC-1	RISC 1	1	$1.0 \times 10^{-6} \leq \Delta CDF$	$0.05 \leq FV < 0.12$	$1.5 \leq RAW < 2.5$	$FR \leq 1 \times 10^{-4}$	$R \geq 0.9999$
1-2	SC-1,2	RISC 1,2	2	$1.0 \times 10^{-7} \leq \Delta CDF < 1.0 \times 10^{-6}$	$0.01 \leq FV < 0.05$	$1.0 \leq RAW < 1.5$	$1 \times 10^{-4} < FR \leq 1 \times 10^{-3}$	$0.999 \leq R < 0.9999$
2	SC-2	RISC 2	2	$1.0 \times 10^{-8} \leq \Delta CDF < 1.0 \times 10^{-7}$	$0 \leq FV < 0.01$	$RAW < 1.0$	$1 \times 10^{-3} < FR \leq 1 \times 10^{-2}$	$0.99 \leq R < 0.9999$
3	SC-3	RISC 3	3	$\Delta CDF < 1.0 \times 10^{-8}$	-	-	$1 \times 10^{-2} < FR$	$R < 0.99$
Non-Safety	Non-Safety	NSG*	-	-	-	-	-	-

*NSG: Non-safety grade

- No reliability target or risk significant criteria

Table 5. PDHRS Risk Importance Metrics

Initiating Event	CDF Contribution	PDHRS Importance (FV)	Comments
Loss of Coolant Accident (LOCA)	2.3E-06/year	0.15	Primary success path
Station Blackout (SBO)	1.8E-06/year	0.22	Only passive system available
Loss of Feedwater	9.5E-07/year	0.08	Multiple success paths
Anticipated Transients without Scram	1.2E-06/year	0.05	Reactor Protection System is dominant
Weighted Average	6.35E-06/year	0.12	Overall significance

Table 6. Graded Application of Design Codes

Component	Traditional Class	RI-PB Class	RISC Class	Applied Code	Justification
Heat Exchanger Tubes	Class 1	SC-2	RISC-2	ASME III, Class 2 + risk-informed exemption from Class 1 NDE	Lower pressure, corrosion-resistant material
Shell & Headers	Class 2	SC-2	RISC-2	ASME III, Class 2	Matches consequence analysis
Support Structures	Class 2	SC-3	RISC-3	ASME III, Class 3	Seismic analysis shows low stress
Valves & Piping	Class 2	SC-2	RISC-2	ASME B31.1 with nuclear augmentations	Passive function, low failure probability