Perspective on the Classification Approaches for Passive and Non-Safety-Rated System and Components for SMRs

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1. Introduction

The reliability of safety-related SSCs (Systems, Structures, and Components) has traditionally been ensured through programs like Quality Assurance (QA), testing, inspections, and surveillance. However, with the advent of risk assessment methods, some non-safety-related SSCs have been identified as important to safety, raising concerns about confidence in their performance. On the other hand, with the rise of risk assessment, some non-safety-related SSCs have been identified as safety-significant, raising concerns about their performance. Conversely, many safety-related SSCs were found to be non-significant by PSA (Probabilistic Safety Assessment) analyses.

Non-safety-related equipment in a nuclear power plant includes components such as auxiliary pumps, HVAC systems, control panels, instrumentation, and support systems that are not classified as safety-related grade. While these systems are not required to function during accident conditions, their reliability plays a crucial role in ensuring stable operation, reducing unplanned outages, and supporting the performance of safety-related systems during accident conditions.

A failure in non-safety-related systems can lead to reduced plant availability or unnecessary reactor shutdowns, all of which impact the plant's economic efficiency and overall performance during operation. Furthermore, failures in these systems may indirectly affect safety systems or create operational challenges that could escalate into more serious issues during accident conditions if not properly managed.

Therefore, a necessity of applying the Design Reliability Assurance Program (D-RAP) to such equipment in nuclear facilities. This program helps identify and eliminate potential weaknesses before equipment is installed and operated. This proactive approach reduces the risk of in-service failures and extends the useful life of plant. The D-RAP does not change requirements for safety-related SSCs but requires special treatment for non-safety-related risk-significant SSCs. Under 10CFR50.69, safety-related SSCs are categorized into "safety-significant" (full treatment) and "non-safety-significant" (reduced treatment).

The objective of the D-RAP is to ensure that the reactor is designed and constructed in alignment with risk insights and key assumptions (e.g., system design, reliability, and availability) derived from analytical methods, such as probabilistic and deterministic analyses. This objective can be achieved through the following methods:

First, the essential elements of D-RAP, which include organization, design control, corrective actions, procedures and instructions, records, and audit plans, should apply throughout the design and construction activities. These elements ensure that the reactor design is consistent with risk insights and that the list of RAP SSCs (Risk-Important Safety Structures, Systems, and Components) is appropriately developed, maintained, and communicated to the relevant organizations.

Second, it is essential to implement appropriate Quality Assurance (QA) programs for all design and construction activities (e.g., design, procurement, fabrication, construction, inspection, and testing). These programs provide control over activities that affect the quality of RAP SSCs. QA controls for safety-related SSCs are defined by 10CFR50, specifically Appendix B, which outlines Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants. QA for non-safety-related RAP SSCs is addressed in Section 17.5 of the Standard Review Plan (SRP). Besides, for applications of Design Certification (DC) or Combined License (COL) under 10CFR52, an implementation of the D-RAP is required during the design and construction phases, in accordance with NRC's SRP 17.4 and ISG-18. The D-RAP identifies and addresses safety-critical SSCs through both probabilistic and deterministic analysis methods, while also outlining additional activities for non-safety but safety-significant SSCs.

Small Modular Reactors (SMRs) are typically designed with inherent safety features and passive safety mechanisms that rely on natural phenomena such as gravity, natural circulation, and heat conduction, instead of active equipment or operator actions. These features are not considered safety-related because the reactor can achieve safe shutdown and maintain core cooling during most design-basis accidents without them. As a result, this design approach provides greater flexibility and cost-effectiveness.

The design approach of SMRs also provides a systematic methodology for evaluating the safety

significance of both safety-class and non-safety-class structures, systems, and components (SSCs), ensuring that all risk-significant elements receive proper attention during the design, construction, and operational phases. While passive systems and components in many SMRs are classified as non-safety-related because they are not credited for performing essential safety functions, they still contribute significantly to overall plant safety. This classification allows for design flexibility and more cost-effective deployment while maintaining a high level of safety.

To ensure the safety and reliability of these novel SMR designs, regulatory frameworks emphasize the application of:

- Risk-Informed Safety Classification (RISC)
- Regulatory Treatment of Non-Safety Systems (RTNSS)
- Design Reliability Assurance Program (D-RAP).

This study reviewed the regulatory position on risk-informed SSC categorization (RISC), regulatory treatment of non-safety systems (RTNSS), and design reliability assurance programs (D-RAP) for the classification approaches of the passive and non-safety-related components for SMRs.

2. SSC Classification Approaches for SMRs

(1) Deterministic Safety Classification

SSCs are classified based on their role in achieving safety functions. The functions and design provisions required to fulfill the main safety functions are systematically identified for all plant states, including all modes of normal operation. Using information from safety assessments, such as the analysis of postulated initiating events, the functions are then categorized based on their safety significance.

From the IAEA SSG-30 [1], it can be deduced what the approach to frequency thresholds used in SSC classification should be. Table 1 can be the relationship between function and severity of consequence.

Table 1. Relationship between function and severity of consequence

Functions credited in the safety assessment	Severity of the consequences if the function is not performed		
	High	Medium	Low
Functions to reach a controlled state after anticipated operational occurrences	Safety category 1	Safety category 2	Safety category 3
Function to reach a controlled stated after design basis accidents	Safety category 1	Safety category 2	Safety category 3
Functions to reach and maintain a safe state	Safety category 2	Safety category 3	Safety category 3
Functions for the mitigation of consequences of design extension conditions	Safety category 2 or 3	Not categorized	Not categorized

Typically, the consequences of losing a safety function are described in terms of radiation doses to workers and/or the general public. Permissible and unacceptable levels of radiation are specified in national regulations, and these are used in the safety classification process to define low, medium, or high levels of consequences.

Figure 1 shows that SSCs are implemented to decrease the probability of an event, and functions are implemented to ensure that the consequences are acceptable with regard to their probability, as they are classified with ‘high’, ‘medium’, and ‘low’ severity.

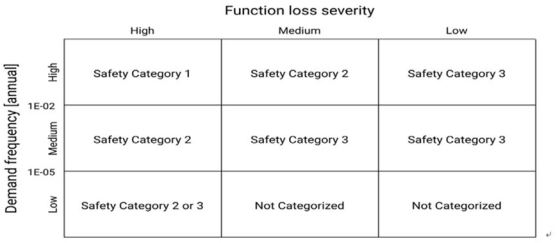

Figure 1. Risk matrix for safety function categorization.

In order to identify the frequency criteria, Figures 2 and 4 show an example of risk matrix that categorizes the safety significance of events based on their frequency and the Defense-in-Depth (DiD) level needed to manage them. These figures are produced based on the Defense-in-Depth Matrix in Reference [9]

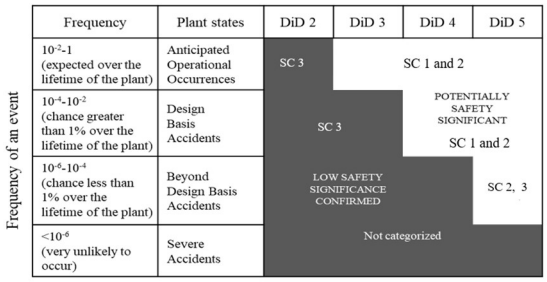

Figure 2. Relationship between functions, DiD, severity of consequence credited in safety classification

Y-axis is divided into four rows, representing the likelihood of an event occurring over the plant's lifetime. The categories range from Anticipated Operational Occurrences (most frequent, 10^{-2} to 1) down to Severe Accidents (very unlikely, less than 10^{-6}).

X-axis shows different plant states and corresponding Defense-in-Depth (DiD) layers (DiD 2 through DiD 5). These layers represent successive barriers or levels of protection against a release of radioactive material.

Safety Classification (SC): The matrix assigns a Safety Class (SC) to different regions, indicating the safety significance of the components required to manage an event.

- SC 1, 2, and 3: These are safety classes assigned to SSCs (Structures, Systems, and Components). The specific classifications depend on the event's frequency and the DiD level it challenges.
- "Low Safety Significance Confirmed": Events in this

region are considered to have low safety significance, likely meaning that components involved do not need to be classified as SC 1, 2, or 3.

- "Potentially Safety Significant": This area indicates that further analysis is needed to determine the exact safety classification.
- "Not categorized": Events in this region, such as severe accidents, are typically beyond the scope of this specific categorization matrix, likely requiring a different type of risk analysis.

In summary, this figure serves as a tool for risk-informed safety classification. It helps engineers and regulators systematically categorize the safety significance of plant SSCs by correlating the frequency of potential events with the level of protection (DiD) they require.

(2) Risk-Informed Safety Classification (RISC)

10CFR50.69 is a Nuclear Regulatory Commission (NRC) regulation that provides a voluntary, risk-informed framework for classifying and treating Structures, Systems, and Components (SSCs) in nuclear power plants. It integrates traditional deterministic safety analysis with probabilistic safety assessment (PSA) to move beyond a simple "safety-related" vs. "non-safety-related" categorization. The core idea is to focus regulatory and maintenance resources on the components that truly matter most for plant safety.

The NRC has proposed 10 CFR 50.69 (1995) which establishes special treatment requirements for plant SSCs with respect to risk-informed categorization.

RISC Categories

The 10 CFR 50.69 rule [2] establishes four distinct Risk-Informed Safety Classification (RISC) categories based on two criteria:

- Traditional Safety Classification: the component originally classified as safety-related or non-safety-related
- Risk Significance: the component make a significant contribution to plant safety based on risk analysis (e.g., PSA).

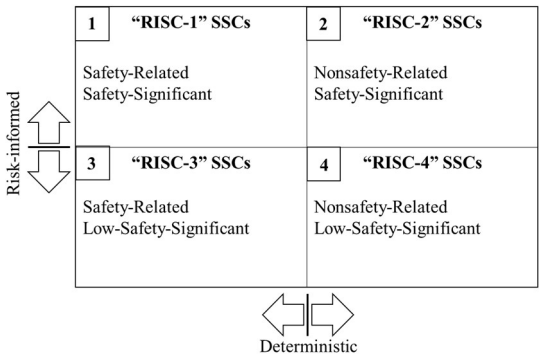

Figure 3 10CFR50.69 RISC Categories

Here is a breakdown of the four RISC categories as follows:

- RISC-1: These are safety-related SSCs that are also determined to be significant contributors to plant safety. They continue to receive the highest level of regulatory oversight and special treatment.
- RISC-2: These are non-safety-related SSCs that are determined to be significant contributors to plant safety. This is a crucial category for SMRs. It ensures that components vital for safety like passive systems or certain support components are identified and receive proper treatment, even if they aren't traditionally safety-related.
- RISC-3: These are safety-related SSCs that are determined to have low safety significance. The benefit of this categorization is that it allows for a reduction in burdensome special treatment requirements for these components, which can lower operational costs without compromising safety. For instance, these components can often be procured using commercial-grade parts instead of more expensive nuclear-grade ones.
- RISC-4: These are non-safety-related SSCs that are also determined to have low safety significance. They continue to receive minimal regulatory oversight.

Figure 4 depicts the internally initiated design basis events considered to identify an SSC as safety-related and considers the level of defense-in-depth available.

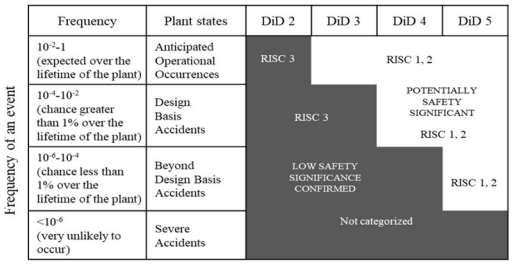

Figure 4. The level of defense-in-depth in preventing core damage and to the frequency of the events being mitigated.

The figure illustrates the relationship between the frequency of an event, the plant state, and the risk significance of a system, structure, or component (SSC) within a nuclear power plant's Defense-in-Depth (DiD) framework. The figure shows how different combinations of event frequency and DiD levels (DiD 2, 3, 4, and 5) are used to categorize an SSC's risk.

- Frequency of an event: This refers to how often a particular event is expected to occur over the lifetime of a nuclear plant. The figure divides this into four categories, from "anticipated operational occurrences" (10^{-2} to 1) to "severe accidents" (<10^{-6}).
- Defense-in-Depth (DiD): This is a multi-layered safety strategy used in nuclear power plants. Each layer provides a barrier to prevent the release of

radioactive materials. The figure shows DiD levels 2 through 5, which relate to preventing core damage and mitigating the consequences of an event.

- Risk Significance: The figure categorizes SSCs as "RISC 3", typically non-safety-related SSCs and "RISC 1, 2," "Potentially Safety Significant," and "Low Safety Significance Confirmed." typically safety-related SSCs.

Significance for SMRs

The RISC framework is particularly important for Small Modular Reactors (SMRs) because of their design philosophy.

- Passive and Non-Safety Components: Many SMR designs rely heavily on passive systems that use natural phenomena (like gravity or natural convection) to provide safety functions. While these systems may not be formally classified as safety-related, a PSA would show they are critical for preventing core damage. The RISC-2 category provides a formal mechanism to identify these components and ensure they receive appropriate design, maintenance, and inspection attention.
- Focus on True Risk: By using a risk-informed approach, the regulatory focus shifts from a broad, deterministic classification to a more precise, risk-based one. This ensures that safety efforts and resources are concentrated on the components that have the greatest impact on overall plant safety, whether they are traditionally safety-related or not.

(3) RTNSS Classification

RTNSS is a regulatory framework originating from the licensing of passive plant designs, like the AP1000. Its purpose is to provide regulatory oversight for non-safety-related but risk-significant Structures, Systems, and Components (SSCs) that are crucial for plant safety and Defense-in-Depth (DiD). Since many advanced reactor designs, especially SMRs, rely on passive and non-safety systems for operational reliability, RTNSS ensures these systems meet sufficient regulatory requirements.

According to the NRC SRP 19.3 and RG 1.206 C.IV.10 [4, 5], the RTNSS process applies to those non-safety-related SSCs that perform risk-significant functions, and are candidates for regulatory oversight. The RTNSS process uses the following five criteria to determine those SSC functions:

- SSC functions relied upon to meet deterministic NRC performance requirements such as Part 50.62 of Title 10 of the Code of Federal Regulations (10 CFR 50.62) for mitigating anticipated transients without scram (ATWS) and 10 CFR 50.63 for station blackout (SBO).
- SSC functions relied upon to ensure long-term safety (beyond 72 hours) and to address seismic events.
- SSC functions relied upon under power-operating and shutdown conditions to meet the NRC's safety goal guidelines of a core damage frequency (CDF) of less than $1x10^{-4}$ each reactor year, and a large release frequency (LRF) of less than $1x10^{-6}$ each reactor year.
- SSC functions needed to meet the containment performance goal, including containment bypass, during severe accidents.
- SSC functions relied upon to prevent significant adverse systems interactions.

RTNSS and Probabilistic Safety Assessment (PSA)

The RTNSS process uses PSA to evaluate the importance of non-safety SSCs. This is typically done through a sensitivity analysis where the Core Damage Frequency (CDF) and Large Release Frequency (LRF) are recalculated.

In this analysis, the non-safety SSCs are assumed to fail or not be credited for accident mitigation. The results are then compared to the regulatory safety goals for CDF and LRF. If the recalculated values are still within the safety goals, these non-safety SSCs are not considered important for the PSA. This provides confidence that accident prevention and mitigation functions will remain effective even without being formally safety-classified.

The importance of non-safety SSCs is determined using three criteria:

- Contribution to Initiating Event Frequency: Does the failure of the non-safety SSC significantly increase the frequency of an initiating event?
- Unavailability of SSCs: Does the unavailability of the non-safety SSC significantly impact the initiating event frequency?
- Contribution to CDF/LRF: Is the SSC's failure a significant contributor (e.g., >10%) to the overall CDF or LRF?

If an SSC fails to meet any of these three criteria, its unavailability is not considered important to the PSA. This methodical approach ensures that regulatory resources are focused on the systems that truly impact plant risk [3].

(4) Reliability Assurance Program (RAP)

Small Modular Reactors (SMRs) are designed to be compact and simplified, often with fewer redundant systems than traditional large reactors. While this design reduces complexity, it makes the high reliability of each individual component essential for ensuring overall plant safety and performance.

However, even though passive components have fewer moving parts, they are not immune to degradation from issues like corrosion, fouling, or thermal aging. Furthermore, many SMRs classify critical systems as non-safety-related. If these non-

safety components fail, they can undermine the effectiveness of the passive safety systems they support (e.g., a non-safety valve failing could block a passive cooling path).

NRC SECY-95-132 provides a clear regulatory framework for passive plant designs, specifically addressing how non-safety systems (RTNSS) should be treated differently from traditional safety systems, with an emphasis on graded safety classifications and a risk-informed regulatory approach. This document reflects the NRC's approach to integrating non-safety-related systems in passive designs, which rely on natural phenomena (e.g., gravity, natural circulation) for safety, and emphasizes flexibility in their regulatory treatment while ensuring overall safety.

In SECY-95-132, both RTNSS and RAP are integral to the risk-informed regulatory approach as the complementary roles for ensuring that the systems' reliability is consistently maintained to prevent failures. RTNSS provides the necessary thermal-hydraulic and nuclear safety insights, helping to identify where specific systems or plant configurations might be at risk under certain operational conditions. RAP provides the reliability monitoring framework, ensuring that systems function properly over time and that corrective actions are taken when necessary to mitigate risks.

Together, RTNSS and RAP form a comprehensive approach to nuclear safety, where RTNSS helps identify potential safety concerns based on thermal and nuclear risks, and RAP ensures that the systems perform reliably and continuously meet the required safety standards.

Both approaches rely on PSA to guide decision-making. RTNSS informs the NRC about potential vulnerabilities in systems related to thermal and nuclear performance, while RAP uses reliability data to evaluate the performance of these systems, ensuring that any risks identified in RTNSS are managed effectively.

Therefore, the Reliability Assurance Program (RAP) is a structured program designed to ensure that risk-significant Structures, Systems, and Components (SSCs) maintain high reliability throughout the plant's lifecycle. It is a key part of the SMR's design and operational strategy, ensuring that both active and passive systems critical for risk reduction are properly monitored and maintained.

Probabilistic Safety Assessment (PSA) in RAP

The treatment approach for SSCs under 10CFR50.69 can provide guidance for developing treatment for SSCs within the D-RAP scope. RISC-2 SSCs are not subject to full Safety Grade treatment, but due to their safety significance, they receive a level of treatment above commercial grade. In contrast, RISC-3 SSCs, originally Safety Grade but deemed less significant to safety, may receive a reduced level of treatment. D-RAP does not address the specific requirements for RISC-3 SSCs, which are treated under deterministic programs. The treatment for Safety Significant but not Safety Related SSCs (RISC-2) within the D-RAP scope is defined by the applicant or licensee.

For new plants, the distinction between D-RAP and RISC-2 treatments, along with the difference from RISC-3 treatment (if 10CFR50.69 is adopted), is a matter of choice. Therefore, the 10CFR50.69 definitions can serve as a guide for D-RAP treatment of within-scope SSCs. Significant work has been done to define treatment for RISC-3 SSCs, which may also inform the treatment approach for D-RAP's within-scope but not Safety-Related SSCs as shown in Table 2.

Table 2 Comparison of SSC Classification with Class Definition and Treatment [9]

SSC CLASSIFICATION	CLASS DEFINITION	TREATMENT
D-RAP Within-Scope SSCs	Safety Related and Safety Significant	Treat as Safety Related i.e. No Change
D-RAP Within-Scope SSCs	Non Safety Related but Safety Significant	"Special" in New Plants Greater than Commercial Treatment
RISC 2 SSCs	Not Safety Related but Safety Significant	"Special" in New Plants Greater than Commercial Treatment
RISC 3 SSCs (only if 10CFR50.69 is adopted)	Safety Related but not safety Significant	"Special" in New Plants Less treatment

RAP uses Probabilistic Safety Assessment (PSA) to determine which components are risk-significant and therefore require increased oversight. Two key PSA importance measures (criteria) are used for this classification:

- Risk Achievement Worth (RAW): This measure quantifies the increase in risk if a specific component fails. A basic event (e.g., a component failure) is considered risk-significant if its RAW is 2.0 or more. This means that if the component fails, the plant's risk (e.g., core damage frequency) would increase by a factor of at least two.
- Fussell-Vesely (FV) Importance: This measure indicates the fraction of the total risk contributed by a specific component or event. A basic event is considered risk-significant if its FV importance is 0.005 or more. This means the failure of that component contributes at least 0.5% to the total plant risk.

By applying these criteria, RAP ensures that resources are focused on maintaining the reliability of the most critical components, regardless of their traditional safety classification.

3. PSA Importance Measures

The criteria for classifying a component as High Safety Significant (HSSC), Intermediate Safety Significant (ISSC), or Low Safety Significant (LSSC)

are based on Probabilistic Safety Assessment (PSA) metrics.

Two most common metrics *are:*

- Fussell-Vesely (FV): This measure indicates the fractional contribution of a component's failure to the total risk (e.g., Core Damage Frequency). A higher FV value means the component's failure accounts for a larger portion of the total risk.
- Risk Achievement Worth (RAW): This measure quantifies the increase in risk if a component is assumed to be failed or unavailable. A RAW value of 2.0 means that the total risk would double if the component were to fail.

Some other metrics include:

- Risk Reduction Worth (RRW): This measure indicates the decrease in risk if a component is always available and reliable. An RRW value of 1.05 means the total risk would be reduced by 5% if the component were to be perfectly reliable.
- Core Damage Frequency (CDF) / Large Early Release Frequency (LERF): These are the top-level risk metrics. The importance of a component can also be measured by the percentage of the total CDF or LERF it contributes to.

Summary of Criteria from Different Sources

The specific numerical thresholds for these measures can vary depending on the regulatory guidance or the application from industry groups and standards:

- ASME Code Case: Classifies a component as an HSSC if its FV > 0.005 or its RAW > 2.
- PSA Application Guide: Has more detailed criteria for both systems and components. For components, an HSSC 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.
- EPRI Pilot Project: Uses both FV and RAW to classify components into high, medium, and low categories. For example, a high-significance component has an FV > 0.01 or RAW > 10.
- NUMARC 93-01: Classifies a component as high safety significant 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.
- WOG Periodic Verification of MOV: Provides two different classification methods, both using combinations of FV and RAW to define HSSCs.
- South Texas: Defines an HSSC as having an FV (for either CDF or LERF) > 0.005.

These various criteria highlight that while the underlying PSA metrics are standard, their application and specific thresholds can be tailored to the context of a particular plant, component, or regulatory program (such as risk-informed in-service testing or the Maintenance Rule).

Fussell-Vesely (FV) and Risk Achievement Worth (RAW) are the primary metrics used to identify safety-significant components in a nuclear power plant. These metrics are part of the PSA process and are used to screen components based on their contribution to top-level risk metrics like Core Damage Frequency (CDF) or Large Early Release Frequency (LERF).

Fussell-Vesely (FV) Importance

The Fussell-Vesely (FV) importance metric measures a component's fractional contribution to the total risk. It tells you what percentage of the total risk is caused by the failure of a specific component.

- Formula: The FV for a component is calculated as the ratio of the total risk from all accident sequences involving that component to the total plant risk.
- NEI 00-04 Criterion: A component is considered a candidate for safety significance if the sum of the FV for all its related events (including common cause failures) is greater than 0.005. This means the component's failure contributes more than 0.5% to the total risk.

Risk Achievement Worth (RAW) Importance

The Risk Achievement Worth (RAW) metric measures how much the total plant risk would increase if a specific component were to fail.

- Formula: RAW is the ratio of the total risk assuming the component is failed to the base-case total risk. A RAW value of 2.0 means that if the component fails, the risk doubles.
- NEI 00-04 Criterion: A component is considered a candidate for safety significance if its maximum RAW value (for either a single failure or a common cause failure) is greater than 2.

Summary of Importance Criteria

According to NEI 00-04 [3], a component (or Structure, System, Component, SSC) is a candidate for safety significance if it meets any one of the following criteria:

- The sum of Fussell-Vesely (FV) values for all its failure events (including common cause failures) is greater than 0.005.
- The maximum Risk Achievement Worth (RAW) for a single component failure is greater than 2.
- The maximum RAW for any applicable common

cause failure event is greater than 2.

If any of these conditions are met, the component is flagged for further review and is likely to be classified as safety-significant, requiring special treatment for design, maintenance, and operation.

4. Integrated Safety Framework for SMR

In Small Modular Reactor (SMR) designs, the application of passive safety technology minimizes the number of traditionally safety-related systems. This means that a large number of components crucial for safety are classified as non-safety-related because they are not directly credited in accident analyses. As a result, frameworks like RISC, RTNSS, and RAP are vital for ensuring overall plant safety and reliability.

Integrated Safety Importance for SMRs

A comprehensive safety framework for SMRs requires an integrated application of three key approaches:

- RISC (Risk-Informed Safety Classification): This process uses Probabilistic Safety Assessment (PSA) metrics (like RAW and FV) to identify and categorize all Structures, Systems, and Components (SSCs) based on their actual contribution to risk. It moves beyond traditional classification to find components that are low-risk but historically classified as "safety-related" and, conversely, to identify high-risk components that are not.
- RTNSS (Regulatory Treatment of Non-Safety Systems): This ensures that non-safety-related but risk-significant SSCs receive appropriate regulatory oversight and quality control. While these components may not directly prevent an accident, their failure can impact the reliability and availability of safety-related equipment.
- RAP (Reliability Assurance Program): This program provides lifecycle assurance that all risk-significant SSCs - both active and passive - maintain high reliability from design through operation and maintenance. It is essential for SMRs, where the high reliability of individual components is critical due to reduced redundancy.

Together, these measures ensure that safety is not confined to a limited number of safety-class systems. By identifying and managing the risk contribution of passive and non-safety-class components, this integrated approach provides a robust safety framework for SMRs.

SMR Passive Equipment Classification

The application of these frameworks leads to a new approach for classifying SMR components, as demonstrated in Table 3 and Table 4. This approach likely uses PSA results to assign a safety or non-safety grade to passive equipment, ensuring their reliability and availability are properly managed based on their risk contribution. This is a crucial step for SMRs because it ensures that even though these passive systems are not traditionally safety-related, their reliability is assured due to their risk-significant role.

5. Conclusions

This study concludes that a combined, risk-informed approach to classifying reactor components is essential for Small Modular Reactors (SMRs). The traditional deterministic method, which simply labels systems as "safety-related" or "non-safety-related," is insufficient for SMRs because their simplified designs and reliance on passive systems mean that many non-safety components are actually critical for safety.

The proposed approach integrates three key frameworks:

- Risk-Informed Safety Classification (RISC): This ensures that all Structures, Systems, and Components (SSCs) are evaluated based on their actual contribution to plant safety, not just their traditional classification.
- Regulatory Treatment of Non-Safety Systems (RTNSS): This provides a formal regulatory framework for overseeing non-safety-related but risk-important systems, ensuring they meet necessary standards.
- Reliability Assurance Program (RAP): This maintains the integrity and performance of all risk-significant SSCs throughout the plant's entire lifecycle.

By combining these three approaches, Small Modular Reactors (SMRs) can achieve a robust safety framework, which in turn helps to build regulatory confidence and enables the efficient, cost-effective deployment of advanced reactors. The study also proposes using specific criteria, such as Core Damage Frequency (CDF), Risk Achievement Worth (RAW) and Fussell-Vesely (FV) importance metrics from a Probabilistic Safety Assessment (PSA), to systematically categorize nuclear components.

ACKNOWLEDGMENT

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Table 3. Proposed Combined-SSC Classification Criteria by Risk Contribution

Classification	Safety Grade	QA Grade	RTNSS (RAW)	FV Grade	ΔCDF Range (1/year)	RAP Reliability Target (Failure rate, FR)
1	RISC 1	1	1.5≤RAW≤2.5	0.05≤FV<0.12	$\Delta CDF \geq 1.0\times10^{-6}$	$FR \geq 1\times10^{-4}$
1-2	RISC 1,2	2	1.1≤RAW<1.5	0.01≤FV<0.05	$1.0\times10^{-7} \leq \Delta CDF < 1.0\times10^{-6}$	$1\times10^{-4} \leq FR < 1\times10^{-3}$
2	RISC 2	2	RAW≤1.0	0≤FV<0.01	$1.0\times10^{-8} \leq \Delta CDF < 1.0\times10^{-7}$	$1\times10^{-2} \leq FR \leq 1\times10^{-3}$
3	RISC 3, NSG*	3			$\Delta CDF < 1.0\times10^{-8}$	$FR \leq 1\times10^{-2}$

* NSG: Non-safety grade

Table 4 Example of Passive Equipment Classification by Grade and Risk Contribution

Component Type	RTNSS Classification	RAP Grade (Reliability Target)	QA Grade (Quality Assurance Level)	Safety Grade	PSA Risk Contribution (RAW / FV / ΔCDF)	Key Characteristics and Management Points
Passive Core Cooling Heat Exchanger	Level 1 (High Risk)	Failure probability ≤ 1.E−4	Level 1	RISC 1	RAW 1.8-2.3 FV 0.07-0.12 ΔCDF is intermediate	Core cooling function, failure significantly increases accident frequency, requires highest level of management.
Passive Safety Injection Valve	Level 1-2 (Medium-High Risk)	Failure probability ≤1E−4 to 1E−3	Level 1-2	RISC 1-2	RAW 1.4-1.7 FV 0.04-0.08 ΔCDF is intermediate to low	Directly impacts safety function Enhanced reliability and maintenance are desired.
Integrated Passive Containment Venting	Level 2 (Medium Risk)	Failure probability ≤1E−3	Level 2	RISC 2	RAW 1.3-1.6 FV 0.03-0.06 ΔCDF is low	Auxiliary accident mitigation function Testing and maintenance can be simplified.
Passive Heat Exchanger (Secondary Loop)	Level 1-2 (Medium-High Risk)	Failure probability ≤1E−4 to 1E−3	Level 1-2	RISC 1-2	RAW 1.5-2.0 FV 0.05-0.09 ΔCDF is intermediate to high	Core decay heat removal function Reliability assurance is important.
Hydrogen Recombiner / Mitigation System	Level 3 (Low Risk)	Failure probability ≤1E−2	Level 3	RISC 3 Non-Safety Grade	RAW 1.0-1.2 FV 0.01-0.03 ΔCDF is very low	Auxiliary safety function Risk impact of failure is negligible.