Comparison and Examples of Risk-informed Safety Classification in Different Countries

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Abstract: PRA is widely used for the risk informed safety classification (RI-SC) of the systems, structures and components in a nuclear power plant. The general target is to verify the safety classification determined by deterministic rules based on probabilistic methods. The methods and implementation of RI-SC vary in different countries. This paper presents the general approach, requirements, typical methods and example results of RI-SC evaluations in the United States and in Finland. In the United States, there are two deterministic safety classes (safety-related and nonsafety-related). In the RI-SC process, components are assigned into four groups: RISC-1 (safety significant, safety-related), RISC-2 (safety significant, nonsafety-related), RISC-3 (low safety significant, safety-related), RISC-4 (low safety significant, nonsafety-related). Reduced component testing, procurement requirements, monitoring and reporting is allowed for low safety significant components. In Finland, there are five deterministic safety classes: SC1, SC2, SC3, EYT/STUK and EYT (non-safety classified). SSCs are assigned into safety classes based on deterministic criteria, and the safety classification shall be verified with RI-SC process. The RI-SC process may lead to increasing a component safety class based on high PRA importance, which increases the quality requirements of the component. The RI-SC process does not generally allow decreasing a component safety class.

Keywords: PRA, Safety classification, Risk Informed Applications, RI-SC

1. INTRODUCTION

PRA is widely used for the risk informed safety classification (RI-SC) of the systems, structures and components (SSCs) in a nuclear power plant. The general target and purpose are to verify the safety classification determined by deterministic rules based on probabilistic methods. However, the methods and implementation of the RI-SC are different in different countries. This paper presents the general approach / method, implementation and examples of RI-SC evaluations in the United States and Finland.

In the United States, 10 CFR 50.69, "Risk-informed categorization and treatment of structures, systems and components for nuclear power reactors" [1] describes the approach for the RI-SC. The US approach for the deterministic SC includes two categories: safety-related and nonsafety-related. Based on the risk-informed application, the plant SSCs can be categorized into two further categories: safety significant and low safety significant. Thus, all the plant SSCs are included in four boxes: RISC-1 (safety significant, safety-related), RISC-2 (safety significant, nonsafety-related), RISC-3 (low safety significant, safety-related), RISC-4 (low safety significant, nonsafety-related). SSCs with low safety significance can be scoped out of several regulations related to leak rate tests, quality requirements, in-service inspections, maintenance rule, etc.

In Finland, there are the following deterministic safety classes: class 1, class 2, class 3, EYT/STUK and non-safety classified. The PRA importances of SSCs shall be calculated with the PRA and compared to the deterministic safety class of the SSC. If the PRA indicates a high importance for a SSC with a low deterministic safety class, it may be necessary to raise the safety class of the component. The main purpose of the RI-SC in Finland is to ensure that all the SSCs that have a high importance based on PRA also have a high safety class.

This paper presents the framework and requirements related to deterministic safety classification and RI-SC in the United States and in Finland (section 2). RI-SC results on example plants are shown in section 3. Discussion and comparison of the approaches are presented in section 4. Summary and conclusion are provided in section 5.

2. CLASSIFICATION AND RI-SC FRAMEWORK

This section presents the framework, main requirements and applied processes for safety classification and RI-SC in the United States and in Finland.

2.1. United States

The framework for deterministic safety classification and the categories in the RI-SC in the United States are shown in Figure 1.

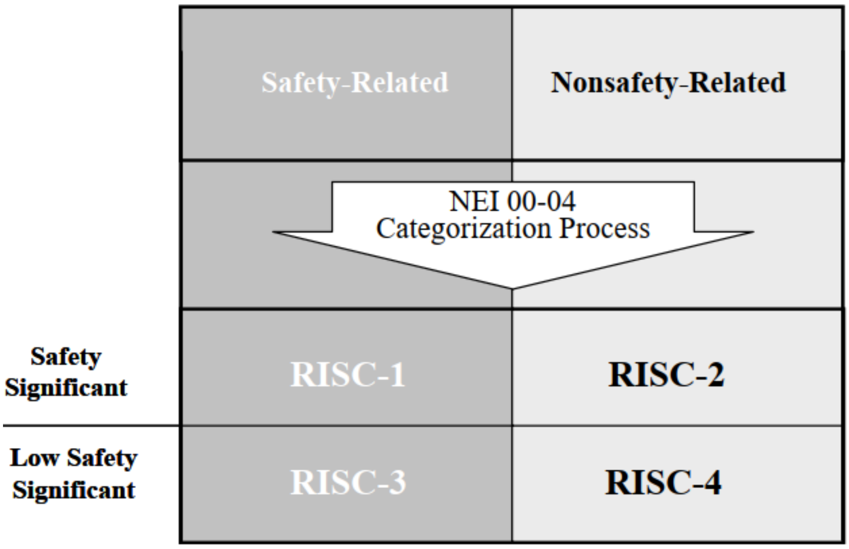

Figure 1. Deterministic safety classification and RI-SC groups in the U.S. [2]

The US regulation related to the RI-SC is provided in the 10 CFR § 50.69 "Risk-informed categorization and treatment of structures, systems and components for nuclear power reactors", which requires the following:

- SSCs must be categorized as RISC-1, RISC-2, RISC-3, or RISC-4 SSCs using a categorization process that determines if an SSC performs one or more safety significant functions and identifies those functions.
- The categorization shall be based on plant-specific PRA with a minimum requirement of internal IEs at full power operation. The PRA shall have adequate quality, level of detail and it shall be peer reviewed.
- The functional importance of SSCs shall be determined with an integrated, systematic process addressing internal and external initiating events, SSCs and different plant operating modes.
- Defense-in-depth shall be maintained.
- For RISC-3 SSCs, sufficient safety margins shall be maintained and the potential increases in CDF and LERF shall be small. The performance of RISC3 SSCs shall be monitored.
- RI-SC shall be performed for entire systems and structures (and not for selected components only).
- The SSCs must be categorized by an Integrated Decision-Making Panel (IDP) staffed with expert, plant-knowledgeable members whose expertise includes, at a minimum, PRA, safety analysis, plant operation, design engineering, and system engineering.
- RI-SC shall be updated in a timely manner and at least every second refueling outage considering changes to the plant, operational practices and applicable plant and industry operational experience.

NEI 16-09 [3] presents a strategic implementation guideline and more detailed implementation guidelines are given by NEI 00-04 [2], RG-1.200 [4], RG-1.201 [5] and EPRI 1015099 [6]. The process for the risk-informed categorization is summarized in Figure 2 [2].

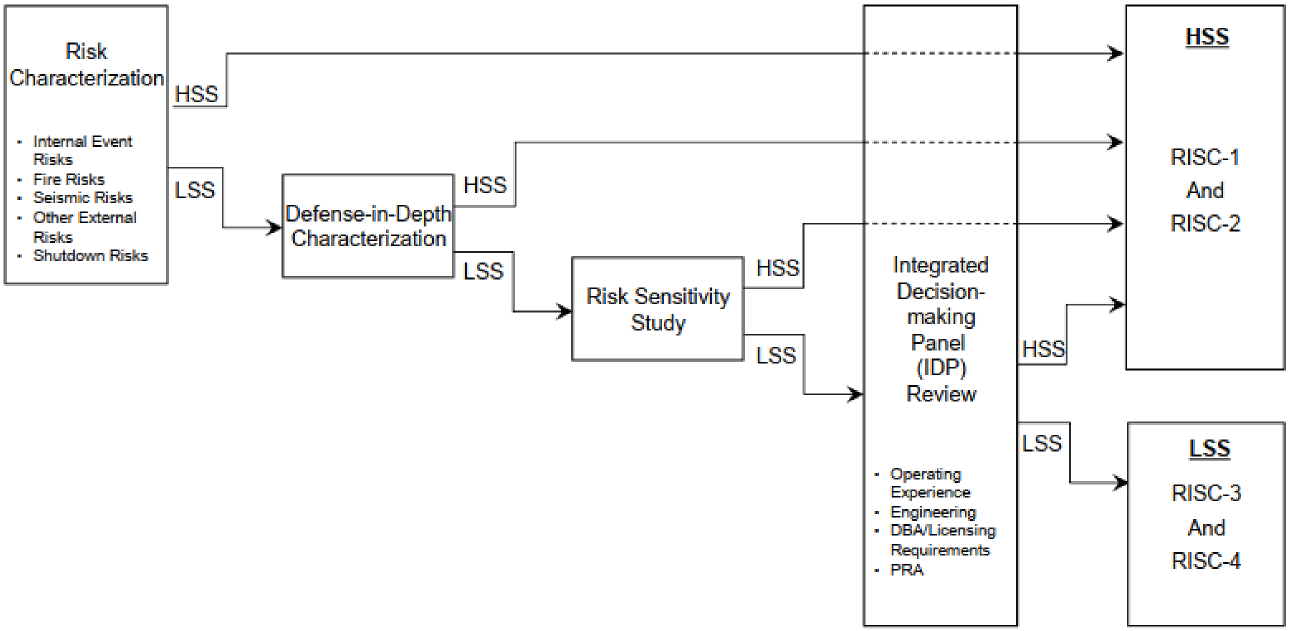

Figure 2. The process for risk-informed categorization in the U.S. [2]

In the PRA-based risk characterization, SSCs are assigned HSS if any of the following criteria are true [2]:

- Sum of FV for all basic events modeling the SSC of interest (including CCFs) > 0.005
- Maximum of component basic event RAW values > 2
- Maximum of applicable common cause basic events RAW values > 20

The defence-in-depth characterization considers core damage and containment defence-in-depth as described in NEI 00-04 [2].

The risk sensitivity study includes the following recommended sensitivity analyses:

- Increase all human error basic events to their 95th percentile value
- Decrease all human error basic events to their 5th percentile value
- Increase all component common cause events to their 95th percentile value
- Decrease all component common cause events to their 5th percentile value
- Set all maintenance unavailability terms to 0.0
- Any applicable sensitivity studies identified in the characterization of PRA adequacy

The final safety significance of SSCs will be determined by the IDP. The IDP is allowed to change the component significance from HSS to LSS only in specific cases, for example if the component is HSS only based on fire or seismic PRA but the result for the integrated assessment is LSS.

The SSCs evaluated as low safety significant (RISC-3, RISC-4) can be scoped out of the US regulations presented in Figure 3. In practice, the requirements can be reduced for component testing, procurement requirements for replacement parts, monitoring and reporting.

Figure 3. The U.S. regulations that can be scoped out for the LSS components.

2.2. Finland

The deterministic safety classification approach in Finland applies both functional and structural aspects. The functional classification criteria categorize SSCs based on their significance for implementing safety functions. The structural classification criteria categorize SSCs based on the structural strength, integrity and leak tightness required of them to prevent the spreading of radioactive substances.

The safety classification requirements are presented in the Finnish YVL Guide B.2 (Classification of systems, structures and components of a nuclear facility, 15.6.2019) [7] issued by the Finnish Radiation and Nuclear Safety Authority (STUK). The safety classes and the related main functional and structural criteria are listed below.

- **Safety Class 1**, including the following SSCs: nuclear fuel, the reactor pressure vessel and those components of the primary circuit whose failure results in a primary circuit leak that cannot be compensated with normal operation systems.
- **Safety Class 2**, including SSCs performing safety functions to manage postulated accidents, to bring the plant to a controlled state (reactivity controlled and decay heat removal secured) and to maintain the controlled state. Safety class 2 also includes primary circuit piping and components that could lead to small leaks that can be compensated with normal operation systems.
- **Safety Class 3**, including SSCs with various safety related functions, such as:
    - managing anticipated operational occurrences
    - bringing the plant to controlled state after severe accidents
    - bringing the plant to safe state (reactivity controlled, decay heat removal secured, reactor depressurized)
    - diverse safety systems
    - nuclear fuel handling and spent fuel cooling
    - fixed radioactivity and dose monitoring
- **Safety Class EYT/STUK**, including systems with additional safety related functions, such as:
    - protection against internal or external events (for example fire prevention and security)
    - radioactivity monitoring
    - managing design extension conditions
    - bringing the plant to safe state after severe accidents
    - diverse cooling of spent nuclear fuel
- **Safety Class EYT** (non-safety significant), including all other SSCs

Stricter quality requirements and quality assurance requirements shall be applied for components in higher safety classes, covering the component design, manufacturing, construction, installation, commissioning, inspections and any actions during the operation.

In accordance with YVL Guide A.7 (Probabilistic risk assessment and risk management of a nuclear power plant, 15.2.2019) [8], the PRA scope shall include:

- Level 1 and Level 2 PRA
- All plant operational states (power operation, low power and shutdown)
- All initiating events (internal events, fires, floods, seismic events, external events), excluding malevolent human acts
- Nuclear fuel in the reactor and spent fuel stored at the plant

The YVL Guide B.2 sets the following requirement on risk-informed safety classification:

> *301. Classification of the nuclear facility's systems, structures and components shall primarily be based on deterministic methods supplemented, and complemented by a Probabilistic Risk Assessment (PRA) and expert judgement.*

The YVL Guide A.7 sets the following requirement on risk-informed safety classification:

> *313. The PRA shall be applied to determine the safety classification of structures, systems and components in accordance with Guide YVL B.2. It shall be ensured by the PRA that the safety classification of every structure, system and component corresponds to its safety significance.*

The RI-SC application shall be submitted to STUK with the actual safety classification document in the construction license (PSAR) phase. The RI-SC shall be updated in the operating license (FSAR) phase and during the plant operation as necessary based on the plant design changes.

The YVL guides do not present or propose any specific method on how to evaluate that the PRA-based safety significance of a component is in accordance with the safety class of the component. The method, approach and the criteria shall be developed and proposed by the licensee.

To summarize, the safety class of a component (or system) is initially determined based on the deterministic principles and rules as described above. After this, the safety classification is verified based on the safety significance determined by PRA. In case a component has a low safety class, such as SC3 or EYT, the high risk significance indicated by the PRA could lead to increasing of the safety class (for example to SC2 or SC3). Lowering the safety class based on the low safety significance indicated by the PRA results is generally not performed in practice because the deterministic criteria shall be followed unless a deviation can be carefully justified.

3. APPLICATIONS AND RESULTS

3.1. United States - Example BWR plant

This section presents results of an actual categorization process for a U.S. example BWR plant with several units. The examples include the residual heat removal system, main steam system and ventilation system of the plant. The system components of all the units were categorized. The PRA calculations were performed with CAFTA. The results as shown in Tables 1, 2 and 3. The group UNCAT represents interfacing system components that could not be categorized until the other interfacing system is categorized as well.

Table 1. Categorization results of an example U.S. BWR plant with several units for the residual heat removal system.

RISC	**Number of components**	**Share (%)**
RISC-1	1677	31.47
RISC-2	27	0.51
RISC-3	1405	26.37
RISC-4	1350	25.33
UNCAT	870	16.32
Total	5329	100.00

Table 2. Categorization results of an example U.S. BWR plant with several units for the main steam system.

RISC	**Number of components**	**Share (%)**
RISC-1	815	12.94
RISC-2	294	4.67
RISC-3	948	15.05
RISC-4	2794	44.34
UNCAT	1449	23.00
Total	6300	100.00

Table 3. Categorization results of an example U.S. BWR plant with several units for the ventilation system.

RISC	**Number of components**	**Share (%)**
RISC-1	6	0.12 %
RISC-2	1	0.02 %
RISC-3	1398	28.32 %
RISC-4	2584	52.34 %
UNCAT	932	18.88 %
Total	4937	100.00

For the residual heat removal system, the categorization process included 3082 safety related components (RISC-1, RISC-3), from which 1405 components (46 %) were evaluated low safety significant (RISC-3).

The categorization process included 1377 non-safety related components (RISC-2, RISC-4), from which only 27 components (2 %) were evaluated high safety significant (RISC-2).

For the main steam system, the categorization process included 1763 safety related components (RISC-1, RISC-3), from which 948 components (54 %) were evaluated low safety significant (RISC-3). The categorization process included 3088 non-safety related components (RISC-2, RISC-4), from which 294 components (10 %) were evaluated high safety significant (RISC-2).

For the ventilation system, the categorization process included 1404 safety related components (RISC-1, RISC-3), from which 1398 components (99.6 %) were evaluated low safety significant (RISC-3). The categorization process included 2585 non-safety related components (RISC-2, RISC-4), from which only 1 component (0.04 %) was evaluated high safety significant (RISC-2).

The results demonstrate that for the residual heat removal system and the main steam system roughly half of the safety related components could be assigned to the LSS category allowing significant reduction for testing, procurement requirements, monitoring and reporting. Only a small part of the non-safety related components were evaluated HSS, which could lead to increased quality requirements. This demonstrates the significant potential benefits of the categorization process. For the ventilation system, the potential benefits were even higher because only few individual components were assigned to the HSS category and a great majority were evaluated LSS.

3.2. Finland

This section presents results of a RI-SC applied on a system-level for a Finnish PWR plant in in the construction license (PSAR) phase.

The PRA-based importance was determined based on the following importance measures:

- CFDP/CCDP, Conditional Fuel/Core Damage Probability (level 1 PRA)
- CLRP, Conditional Large Release Probability (level 2 PRA)
- FC, Fractional contribution
- FV, Fussell-Vesely Importance
- RIF, Risk Increase Factor

The determination of PRA-based risk importance based on two-dimensional mapping of RIF and FC is shown in Figure 4. Similarly, the determination of PRA-based risk importance based on CFDP (or CLRP) and FV are shown in Figure 5.

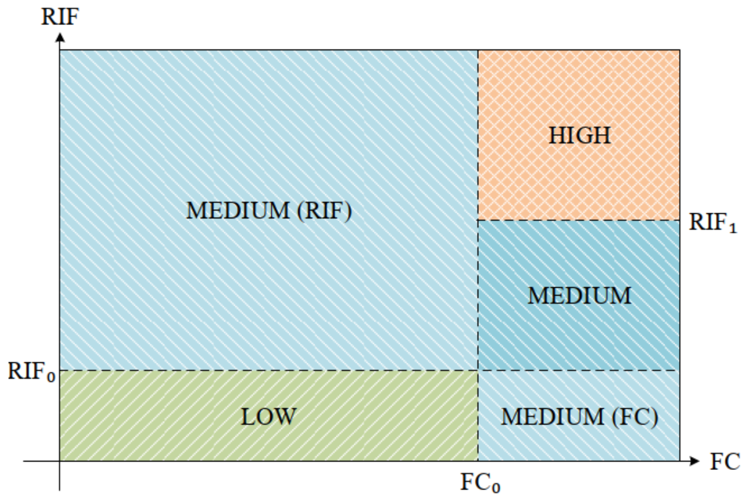

Figure 4. Determining the PRA importance based on two-dimensional mapping of RIF and FC. The limit values applicable to both level 1 and level 2 PRA are: RIF_0=2, RIF_1=10, FC_0=0.005.

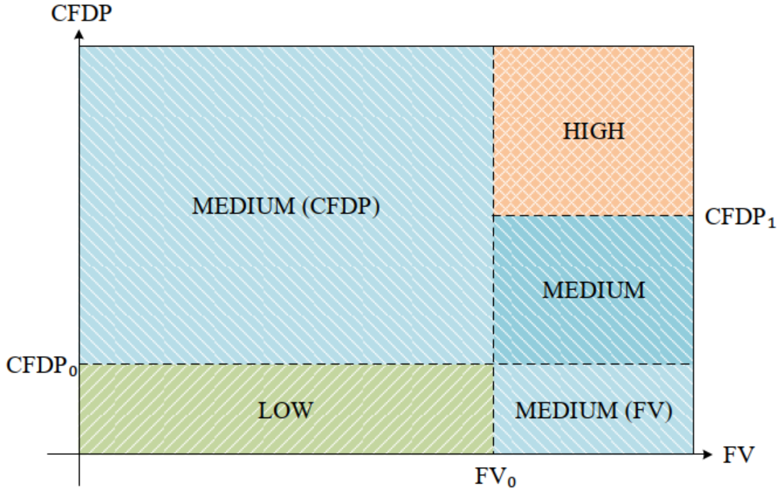

Figure 5. Determining the PRA importance based on two-dimensional mapping of CFDP and FV for level 1 PRA. The evaluation is similar for CLRP and FV for level 2 PRA. The limit values are: $CFDP_0=10^{-6}$, $CFDP_1=10^{-4}$, $CLRP_0=10^{-7}$, $CLRP_1=10^{-5}$, $FV_0=0.005$.

Figure 6 shows the distribution of systems belonging to different safety class and risk class groups based on level 1 PRA (CDF) and level 2 PRA (LRF). The PRA calculations were performed with RiskSpectrum.

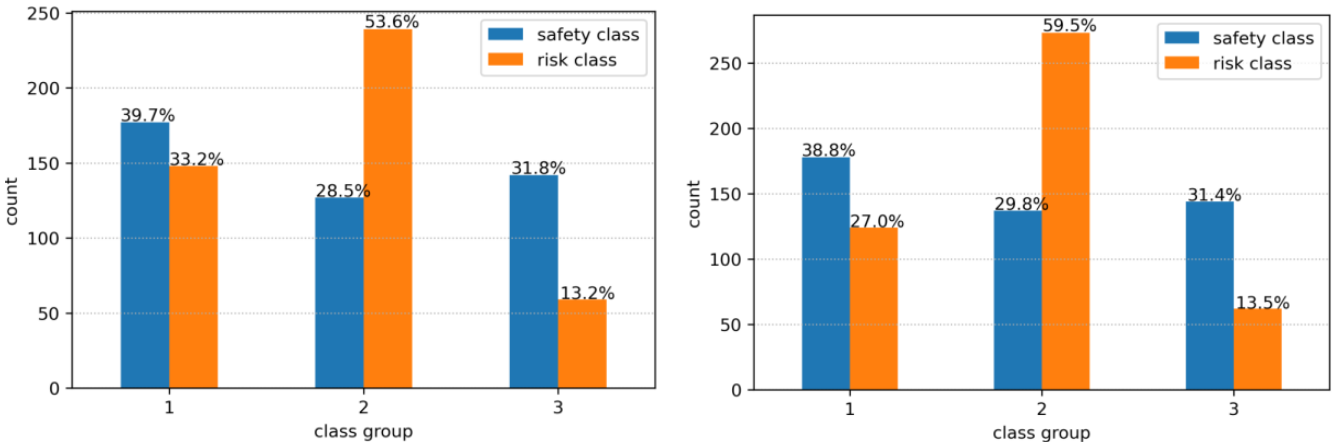

Figure 6. Distribution of systems to safety classes (group 1 = SC1, SC2; group 2 = SC3, group 3 = EYT/STUK, EYT) and risk classes (group 1 = HIGH PRA importance; group 2 = MEDIUM PRA importance, group 3 = LOW/NONE PRA importance). The left figure shows the results for level 1 PRA and the right figure for level 2 PRA.

Figure 7 shows the two-dimensional mapping of systems based on level 1 PRA importance values RIF-FC (upper left figure) and CCDP-FC (lower left figure) and level 2 PRA importance values RIF-FC (upper right figure) and CLRP-FC (lower right figure). The deterministic safety class of each system is indicated with different colors.

The RIF and FC importance values show quite a good consistency between the deterministic safety class and the PRA importance. There are more discrepancies in the CCDP and CLRP mappings indicating for example that some non-safety classified systems (EYT) have a medium or high PRA importance. Furthermore, the SC2 systems have generally low CCDP and CLRP. In general, there are several systems in lower safety classes SC3, EYT/STUK and EYT with a medium or high PRA importance, which may indicate a need to consider raising the deterministic safety class for some components in these systems.

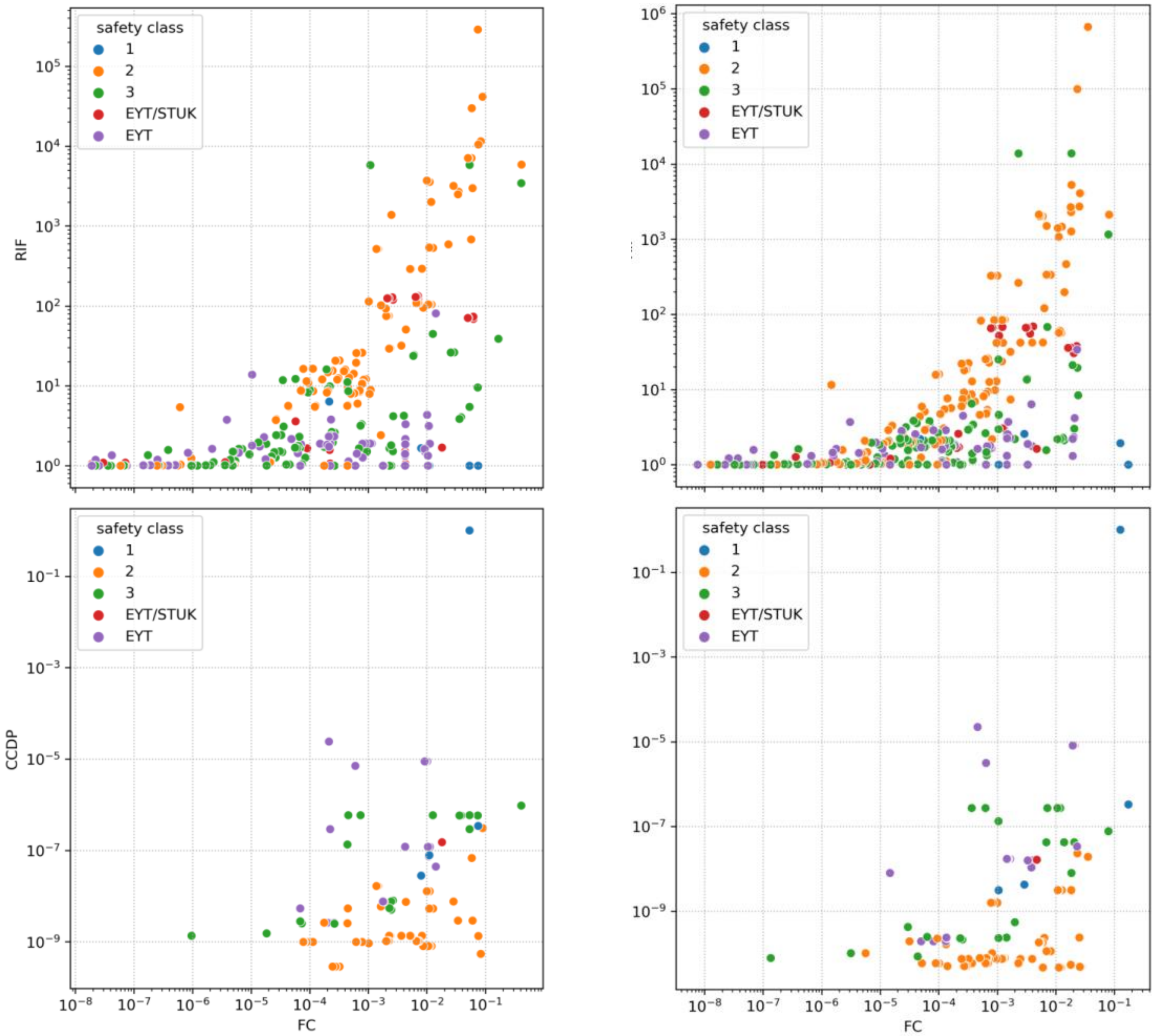

Figure 7. Two-dimensional mapping of systems: upper left - RIF-FC (level 1); lower left - CCDP-FC (level 1); upper right - RIF-FC (level 2); lower right - CLRP-FC (level 2). The deterministic safety classes are indicated with different colors.

Table 4 presents a more detailed listing of systems with major discrepancies between the deterministic safety class and PRA importance.

It shall be noted that the PRA importance evaluation against the deterministic safety class was performed only on a system level. The same evaluation is required to be performed on a component level, and this could reveal component level needs to raise the safety class, which would in practice impact the component level quality requirements. Anyway, the system level evaluation already provides useful insights on which systems probably include components with a low deterministic safety class and a high PRA importance.

Table 4. List of systems with major discrepancies between the deterministic safety class and PRA importance (risk class).

System	Safety class	Risk class
Residual heat removal system	SC3	HIGH
Reactor emergency cooldown system	SC3	HIGH
Low voltage power supply system of equipment for severe accidents control and management	SC3	HIGH
Chilling medium supply system of ventilation system train D	EYT/STUK	HIGH
Chilling medium supply system of ventilation system train B	EYT/STUK	HIGH
Generator of station blackout diesel generator station, train A	SC3	HIGH
System of passive heat removal through steam generators	SC3	HIGH
Generator of station blackout diesel generator station, train B	SC3	HIGH
Chilling medium supply system of ventilation system train A	EYT/STUK	HIGH
Chilling medium supply system of ventilation system train C	EYT/STUK	HIGH
Supply-exhaust ventilation system for control building rooms train B and D	SC3	HIGH
Supply-exhaust ventilation system for control building rooms train A and C	SC3	HIGH
Medium voltage normal operating power supply system	EYT	HIGH
Feedwater piping system	EYT/STUK	MEDIUM
DEC uninterrupted reliable power supply system	SC3	HIGH
Turbine bypass system	EYT	MEDIUM
Intermediate pressure cylinder system	EYT	MEDIUM
Low pressure cylinder system	EYT	MEDIUM
Turbine bearings	EYT	MEDIUM

4. COMPARISON OF DIFFERENCES

This section evaluates the main differences in the risk-informed categorization approach in the U.S. and in Finland.

The categorization approach in the U.S. includes the following features:

- The deterministic safety classification includes two classes: safety-related, non-safety related.
- The minimum PRA scope is limited to internal events at power.
- A standard and detailed method has been developed and is widely used in the industry.
- The categorization process allows significant reduction in testing, procurement requirements, monitoring and reporting for components evaluated low safety significant. This follows the graded approach.

The categorization approach in Finland includes the following features:

- The deterministic safety classification combines both structural and functional classification criteria and includes 5 classes: SC1, SC2, SC3, EYT/STUK, EYT (non-safety).
- A full-scope PRA is required (level 1 and 2, all initiating events, all operating modes, all nuclear fuel).
- The licensees develop and apply individual categorization methods and criteria, no standard method used in the industry.
- The categorization process verifies the consistency of the deterministic safety class and PRA importance, which may lead to increase of the component deterministic safety class and quality requirements.

The main target of the two approaches is fundamentally different. In the U.S. approach, the quality requirements of safety related LSS components may be decreased and increased for non-safety related HSS components. In the Finnish approach, the categorization process ensures that there are no components that would have a too low deterministic safety class based on PRA importance.

In general, the following good practices and recommendations can be recognized:

- A clear deterministic classification framework that is internationally harmonized
- A full-scope PRA provides the best insights for risk-informed applications
- A standardized method used within the industry
- Application of the graded approach by assigning stricter quality requirements to components with high PRA importance and lower quality requirements to components with low PRA importance

4. SUMMARY AND CONCLUSIONS

This paper presented the risk-informed safety classification approach in the U.S. and in Finland. The deterministic safety classification framework and the risk-informed categorization approach in these countries was explained. The paper also presented actual application results for an example U.S. BWR plant and a Finnish PWR plant. The U.S. example included a detailed categorization process on a component level for three different systems, whereas the Finnish example was limited to system level evaluation.

The paper also compared the main differences in the approaches in the two countries. In the U.S., the quality requirements of safety related components with low PRA importance may be decreased and increased for non-safety related components with high PRA importance. In Finland, the categorization process ensures that there are no components that would have a too low deterministic safety class based on PRA importance.

The paper recognized good practices and recommendations related to the risk-informed categorization process, including a full-scope PRA, a standardized categorization method and application of the graded approach.

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