Development of a Burden Importance Measure for Dynamic Probabilistic Safety Assessment

Kyeong Seo Kim[a], **Seung Jun Lee**[b*]

[a] Ulsan National Institute of Science and Technology, Ulsan, Republic of Korea,
smart2439@unist.ac.kr
[b*] Ulsan National Institute of Science and Technology (UNIST), Ulsan, Republic of Korea,
sjlee420@unist.ac.kr

Abstract: Dynamic probabilistic safety assessment (DPSA) can represent accident sequences with explicit timing, hardware states, operator actions, and thermal-hydraulic responses. Conventional importance measures remain essential for risk-informed decision making, but they usually rank components by changes in endpoint risk, such as core damage frequency or a binary sequence outcome. This paper proposes a core-water-level burden importance measure for DPSA. The measure uses the probability of each dynamic scenario and a severity burden derived from the core-water-level peak indicator used to determine core-damage status. The burden is defined as an exponential function of the normalized distance between the scenario value and the core-water-level criterion. A user-specified weight assigns a larger burden to scenarios that exceed the criterion. Scenario importance is the product of scenario probability and burden, and the total importance is the sum over all scenarios. Component-level RAW is obtained by recalculating the total importance after setting the component failure probability to one. The proposed measure preserves the interpretability of RAW while adding a trajectory-based severity term that can distinguish near-threshold and beyond-threshold dynamic sequences.

Keywords: Dynamic probabilistic safety assessment; importance measure; core water level; RAW; risk-informed safety assessment; burden metric

---

1. INTRODUCTION

Probabilistic safety assessment (PSA) uses accident sequence models to identify dominant contributors to plant risk. In nuclear applications, importance measures such as risk achievement worth (RAW), risk reduction worth (RRW), Fussell-Vesely (FV), and Birnbaum importance have been used to rank structures, systems, and components (SSCs), to support risk-informed regulation, and to guide prioritization of surveillance, maintenance, and design improvement [1, 2]. These measures are useful because they map a complex risk model into ratios or differences that are easy to interpret. For example, RAW expresses how much the risk metric increases when a component is assumed failed, and RRW expresses the maximum reduction achievable when the component is assumed perfectly available [1, 2].

The limitation is not the concept of importance itself. The limitation is the response quantity to which importance is applied. Conventional PSA frequently reduces an accident sequence to an endpoint, such as core damage or no core damage. This reduction is necessary in many event-tree and fault-tree applications, but it can remove information that is available in a dynamic simulation. Two sequences can both avoid core damage while having different thermal-hydraulic margins. One sequence may approach a core-damage criterion with little recovery time, while another may keep a large margin throughout the transient. In a binary endpoint model, these two cases can receive the same consequence state even though their safety margins are not equivalent.

Dynamic probabilistic safety assessment (DPSA) was developed to treat accident progression as a time-dependent process. Dynamic reliability and dynamic PSA methods allow stochastic hardware states, control actions, operator actions, and physical process variables to interact during the scenario evolution [3, 4]. This capability is important for nuclear safety because accident outcomes depend on event ordering, actuation timing, recovery timing, and thermal-hydraulic feedback. Applications of dynamic PSA to nuclear accident sequence analysis show that the timing of safety injection, operator action, and system recovery can change the interpretation of accident precursors and mitigation success [5].

Recent DPSA studies also emphasize that a dynamic model can generate a richer scenario space than a static event tree. Risk triplets and multi-fidelity dynamic simulations explicitly separate timing, frequency, and consequence information [6]. Simulation optimization methods have also been proposed to reduce the computational cost of DPSA while preserving the ability to search important dynamic sequences [7]. These developments improve the treatment of time, but the final importance ranking may still be dominated by endpoint probability if the thermal-hydraulic response is converted to a binary label before importance is calculated.

Thermal-hydraulic system codes provide information that is directly relevant to performance-based safety evaluation. For example, MARS-KS calculations can provide time histories of peak cladding temperature (PCT), core water level, pressure, flow, actuation time, and operator action time. MARS-KS has been used as a regulatory thermal-hydraulic analysis code in Korea, and continuing code-improvement work demonstrates its role in reactor safety analysis [8]. Integrated deterministic-probabilistic safety assessment research also shows the need to combine probabilistic accident sequence information with deterministic plant response calculations rather than treating them as separate analyses [9].

This paper develops a new DPSA importance measure that uses the core-water-level peak indicator as the performance variable. The core-water-level criterion is treated as the value used to determine whether a dynamic scenario enters the core-damage side of the decision boundary, analogous to the use of a PCT peak criterion in LOCA acceptance evaluation. The proposed measure does not replace CDF, RAW, RRW, FV, or Birnbaum importance. Instead, it defines a burden-based response variable and then applies familiar importance-measure logic to that response.

The central idea is simple. Each dynamic scenario has a probability and a scenario burden. The burden increases exponentially with the normalized distance between the scenario core-water-level peak indicator and the core-water-level criterion. If the scenario exceeds the criterion, the burden is multiplied by a larger user-defined weight. If it does not exceed the criterion, a lower user-defined weight is used. The scenario importance is the product of scenario probability and scenario burden. The total importance is the sum of scenario importance over the DPSA scenario set.

This structure addresses three gaps in conventional endpoint-based importance measures. First, it distinguishes scenarios that have the same binary outcome but different distances from the decision criterion. Second, it preserves the probability weighting required for risk-informed decision making. Third, it allows component-level RAW to be calculated by setting the failure probability of a selected component to one and recalculating the total burden importance. The result is an importance measure that keeps the operational meaning of RAW while adding a trajectory-informed severity term.

The proposed measure is intended for DPSA studies in which scenario probabilities and thermal-hydraulic outputs are available for the same scenario identifiers. It is especially relevant when the analyst wants to rank components or events not only by their effect on core-damage probability but also by their effect on the severity of core-water-level degradation. The method is also compatible with later extensions that use multiple variables, such as PCT, pressure, safety injection flow, or operator time margin. This paper focuses on the core-water-level version to keep the definition transparent and directly implementable.

2. METHOD

2.1. Scenario Set and Required Data

Let S denote the DPSA scenario set. Each scenario s in S represents one sampled or enumerated accident path, including initiating event, equipment states, recovery events, operator actions, and thermal-hydraulic response. The method requires two outputs for each scenario: the scenario probability P_S and the core-water-level peak indicator C_S used for core-damage classification. The probability P_S is obtained from the DPSA model. The value C_S is obtained from post-processing of the thermal-hydraulic simulation or from the scenario-level response database.

The sign convention for C_S must be fixed before the burden calculation. In this paper, C_S is defined as a severity-oriented core-water-level peak indicator. Therefore, larger C_S means a more severe core-water-level condition, and $C_S \geq C_{crit}$ denotes that the scenario exceeds the core-water-level criterion used for core-damage classification. If the raw thermal-hydraulic variable is a water level for which lower values are more severe, the analyst should first transform it into a deficit-type indicator, such as the maximum normalized shortage from the required core water level. This convention keeps the burden formula monotonic with severity.

2.2. Core-Water-Level Burden

For each scenario, the proposed burden B_S is defined as

$$B_S = e^{w_S \frac{C_S - C_{crit}}{C_{crit}}}. \ (1)$$

Here, $C_{crit}$is the core-water-level criterion that separates the non-core-damage side from the core-damage side, and w_S is a user-specified weight. The weight is selected according to whether the scenario exceeds the criterion:

$$w_S = w_{CD}, if\ C_S \geq C_{crit};\ w_S = w_{NCD}, if\ C_S < C_{crit}. \ (2)$$

In the implementation considered here, w_{CD} = 5 and w_{NCD}= 1 are used as default values. These values are not universal constants. They are analyst-defined parameters that express how strongly beyond-criterion scenarios should be penalized relative to below-criterion scenarios. A larger w_{CD} increases the separation between scenarios that exceed the core-water-level criterion and scenarios that remain below it.

Equation (1) has three useful properties. First, B_S = 1 when $C_S = C_{crit}$. Second, B_S increases above one when the scenario moves beyond the criterion. Third, B_S remains positive for all scenarios, which makes it suitable for ratio-type importance measures such as RAW. The exponential form also avoids a discontinuity in the burden value itself at the criterion. The discontinuity is introduced only through the user-selected weight, which represents the analyst decision to penalize core-damage-side scenarios more strongly.

The burden is dimensionless because the deviation from the criterion is normalized by C_{crit}. This normalization allows different plant cases or sequence groups to be compared as long as the same criterion definition and sign convention are used. If the core-water-level criterion is close to zero, a separate normalization scale should be used instead of C_{crit} to avoid numerical instability.

2.3. Scenario-Level and Total Importance

The scenario-level importance measure I_S is the probability-weighted burden of scenario s:

$$I_S = P_S \times B_S. \ (3)$$

The total importance for the full DPSA scenario set is then

$$I_0 = \sum_{s\ in\ S} P_S \times B_S. \ (4)$$

The subscript 0 denotes the baseline plant model or baseline component reliability condition. Equation (4) is the expected burden over the DPSA scenario set. It is analogous to an expected risk metric, but the consequence term is not a binary core-damage indicator. The consequence term is a continuous burden based on the core-water-level response.

This definition separates two effects that are often mixed in a binary endpoint model. The first effect is frequency: a scenario with larger P_S contributes more to I_0. The second effect is severity: a scenario with a larger exceedance of the core-water-level criterion contributes more through P_S. A low-probability scenario can still be important if its burden is large, and a high-probability scenario can dominate the total importance if it remains close to the criterion for many sampled cases.

The contribution fraction of each scenario can be reported as

$$f_S = \frac{I_S}{I_0}. \ (5)$$

This diagnostic quantity is useful for checking whether the total importance is dominated by a small number of scenarios. It also supports traceability because the analyst can identify which accident paths, equipment states, or timing combinations produce the largest probability-weighted burden.

2.4. Component-Conditioned IM+ and RAW

To calculate the importance of a component, event, or basic event i, the DPSA model is recalculated under a forced-failure condition. In this condition, the failure probability of i is set to one. The other event probabilities and model logic are kept consistent with the selected PSA modeling assumptions. The scenario probabilities under this condition are denoted P_s^{i+}. The corresponding total burden importance is

$$I_o^+ = \sum_{s\ in\ S^{i+}} P_s^{i+} \times B_s^{i+}. \ (6)$$

If the forced failure changes the reachable scenario set, S^{i+} denotes the scenario set generated or retained under that condition. If the same scenario identifiers are used, S^{i+} can be treated as S with updated probabilities and updated thermal-hydraulic responses where applicable. The most rigorous implementation reruns or updates the DPSA/thermal-hydraulic coupling when the forced failure changes actuation, flow, timing, or mitigation success.

The burden-based RAW of component i is then defined as

$$RAW_i^B = \frac{I_i^+}{I_0}. \ (7)$$

This value is interpreted in the same direction as conventional RAW. If RAW_i^B = 3, the total probability-weighted core-water-level burden becomes three times larger when component i is forced to fail. The difference is that the denominator and numerator are not endpoint core-damage probabilities. They are expected burden values that account for both scenario probability and distance from the core-water-level criterion.

These extensions are optional in the present paper. The primary target is RAW because the user case requires IM+ obtained by setting the component failure probability to one.

2.5. Calculation Procedure

The calculation procedure is as follows. First, generate or collect the DPSA scenario set and baseline scenario probabilities. Second, run or retrieve the thermal-hydraulic response for each scenario and extract the core-water-level peak indicator. Third, define C_{crit} and confirm that the sign convention makes larger C_S more severe. Fourth, assign w_{CD} and w_{NCD}. In the base calculation, w_{CD} = 5 and w_{NCD} = 1. Fifth, calculate B_S from Eq. (1), I_S from Eq. (3), and I_0 from Eq. (4). Sixth, select a component or event i, set its failure probability to one, and recalculate scenario probabilities and scenario responses as required. Seventh, calculate I_i^+ from Eq. (6) and RAW_i^B from Eq. (7).

The procedure should be implemented with a fixed post-processing rule. The same time window, same core-water-level criterion, same transformation of raw level to severity indicator, and same weight pair should be used for all compared cases. Otherwise, differences in the importance measure may reflect post-processing choices rather than differences in plant behavior.

When the forced-failure condition affects only the probability of pre-existing paths, B_S may be reused from the baseline thermal-hydraulic simulations. When the forced-failure condition changes the accident progression, B_S must be recalculated from the modified thermal-hydraulic response. For example, forcing an injection pump to fail can change safety injection flow, core water level, pressure, and timing. In that case, using only the baseline burden would underestimate the physical effect of the forced failure.

The method can be implemented in either a discrete scenario table or a Monte Carlo sample. In a discrete table, each row contains scenario_id, P_S, C_S, exceedance flag, w_S, B_S, and I_S. In a Monte Carlo sample, P_S can be represented by sample weights. The summations in Eqs. (4) and (6) are then replaced by weighted sample sums. This form is consistent with dynamic PSA estimators that compute risk from weighted simulation outputs [4, 6, 7].

3. CASE STUDY

This case study applies the core-water-level burden importance measure to a MARS-KS based dynamic probabilistic safety assessment (DPSA) model. The objective is to compare the burden-based importance of the HPSI signal delay and the HPSI pump. Conventional PSA importance measures, including RAW, RRW, FV, and Birnbaum importance, rank components by the change in a selected risk metric [1, 2]. DPSA allows the same ranking logic to be applied to a time-dependent thermal-hydraulic response rather than to a binary endpoint alone [3, 4]. In this study, the response metric is the probability-weighted burden associated with the core water level.

The thermal-hydraulic model used for the case study is shown in Figure 1. The model was developed in MARS-KS and used to generate the core water level trajectory for each dynamic scenario. MARS-KS provides system-level thermal-hydraulic responses that can be coupled with probabilistic scenarios for integrated safety assessment [5, 6]. The nodalization in Figure 1 is therefore the deterministic calculation basis for the burden term. The probabilistic part defines the timing and failure conditions of the credited safety functions.

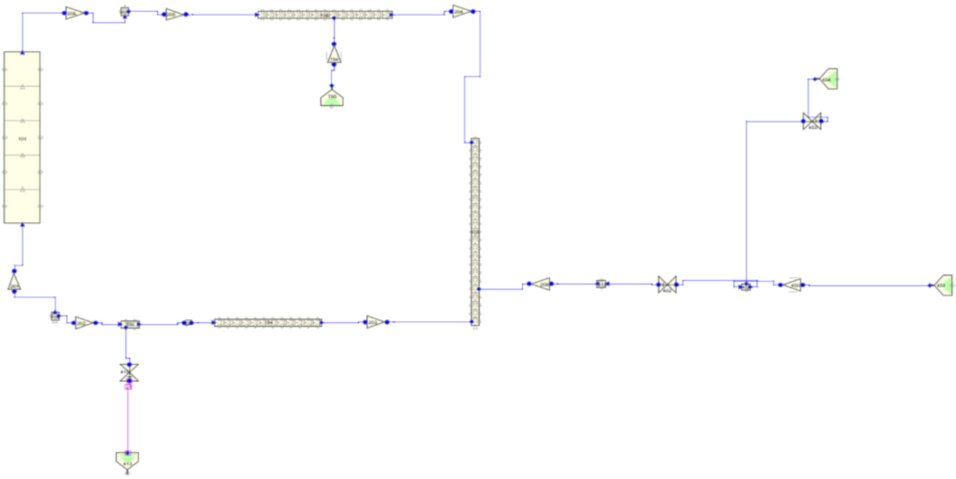

Figure 1: TH model nodalization used in the MARS-KS case study

The credited safety systems are limited to high-pressure safety injection (HPSI) and the safety injection tank (SIT). No other safety system is credited in the case study. The break size is fixed at 0.0039 m^2. The mission time is 10 h, corresponding to 36,000 s. All equipment actuation times, delay times, and failure times are discretized from 0 to 36,000 s with a 3,600 s interval. Core damage (CD) is assumed when the core water level decreases to 20% or lower. The minimum core water level in each transient is used as the performance variable for the burden calculation.

All time-dependent input probabilities are assigned by a left-bin rule. For a discrete time point n, the interval is defined as

$$I_n = \begin{cases} \varnothing, & n = 0, \\ [\max(0, n - 3600), n], & n > 0 \end{cases} \quad (8).$$

Thus, the probability at n = 0 s is zero. For n > 0 s, the probability is the probability mass in the previous 3,600 s interval. For example, n = 3,600 s uses the interval from 0 to 3,600 s, n = 10,800 s uses the interval from 7,200 to 10,800 s, and n = 36,000 s uses the interval from 32,400 to 36,000 s. This definition avoids assigning future probability mass to an earlier time point and keeps the time discretization consistent with the 10 h mission time.

Five input variables are considered. The first variable is the HPSI signal delay time, denoted by P_{signal}. It follows a shifted lognormal distribution with μ = 0.624, σ = 1.172, PMA = 6.0E-4, and a shift of 750 s. The left-bin probability is calculated by the CDF difference

$$P_{signal}(n) = F_{SLN}(u_n) - F_{SLN}(l_n) \ (9),$$

where l_n = max(0, n - 3600), u_n = n, and F_{SLN} is the shifted lognormal CDF. The probability is set to zero at n = 0 s. This variable represents the timing uncertainty in the HPSI actuation signal.

The second variable is the HPSI MOV valve failure and actuation time, denoted by P_{valve}. The model uses an exponential run-failure distribution with a start failure probability of 1.39E-3 and a failure rate of 346/593626 per hour. Because the input time is in seconds, the internal calculation converts time to hours. The cumulative failure probability is written as

$$F_{valve}(t) = P_{start,valve} + \left(1 - P_{start,valve}\right)(1 - \exp[-\lambda_{valve} t_{hr}])\ (10).$$

The left-bin probability is $F_{valve}(u_n)$- $F_{valve}(l_n)$. The value is set to zero at n = 0 s. This model separates the initial demand failure probability from the run-failure contribution accumulated during operation.

The third variable is the HPSI pump failure time, denoted by P_{pump}. It uses a piecewise exponential run-failure model. The start failure probability is 5.66E-4. The failure rate is λ_1 = 18/10670 per hour from 0 to 1 h and λ_2 = 8/3295 per hour after 1 h. The break time is therefore 3,600 s. The cumulative hazard is

$$H(t_{hr}) = \lambda_1 \min(t_{hr}, 1) + \lambda_2 \max(0, t_{hr} - 1)\ (11),$$

and the cumulative pump failure probability is

$$F_{pump}(t) = P_{start,pump} + \left(1 - P_{start,pump}\right)(1 - \exp[-H(t_{hr})])\ (12).$$

The left-bin probability is $F_{pump}(u_n)$ - $F_{pump}(l_n)$, with zero probability at n = 0 s. The pump model is important because the HPSI pump provides sustained injection after the signal and valve actuation occur. A pump failure can therefore affect the core water level over a large part of the 10 h mission time.

The fourth variable is the SIT delay term, denoted by $P_{SIT\ delay}$. It is modeled as a gamma-uncertain exponential failure-rate model for accumulator fails-to-operate behavior. The gamma parameters are alpha = 11.5 and beta = 7.93E+07, where beta is interpreted as a rate parameter and lambda is in units of per hour. The mean failure rate is alpha/beta, approximately 1.45E-7 per hour. The predictive survival function is

$$S_{SIT}(t) = \left(\frac{\beta}{\beta + t_{hr}}\right)^{\alpha}\ (13).$$

The left-bin probability is $S_{SIT}(u_n)$ - $S_{SIT}(l_n)$. This term is nearly constant over 1 h bins and remains close to 1.45E-7. It should be interpreted as an accumulator fails-to-operate model, not as a physical delay-time distribution for SIT injection.

The fifth variable is the SIT valve actuation term, denoted by $P_{SIT\ valve}$. It represents an explosive-operated valve failure-to-open demand probability. The beta distribution parameters are alpha = 1.010 and beta = 217.0. The mean demand failure probability is

$$E[P_{SIT\ valve}] = \frac{\alpha}{\alpha + \beta} = 4.632815 \times 10^{-3}\ (14).$$

Because this model is a demand failure probability rather than a time-to-failure distribution, it is not integrated over a time bin. The value is zero at n = 0 s. For n > 0 s, $P_{SIT\ valve}$ is set to 4.632815E-3 when the SIT actuation demand exists.

The scenario burden is calculated from the minimum core water level. Let $L_{min,s}$ be the minimum core water level of scenario s and let L_{crit} = 20%. The burden is

$$B_s = \exp\left[w_s \frac{L_{crit} - L_{min,s}}{L_{crit}}\right]\ (15).$$

The weight is 5 when $L_{min,s}$ is less than or equal to the CD criterion and 1 otherwise:

$$w_s = \begin{cases} 5, & L_{min,s} \le L_{crit}, \\ 1, & L_{min,s} > L_{crit} \end{cases}\ (16).$$

The scenario importance and baseline total importance are

$$I_s = P_s \times B_s, \qquad I_0 = \sum_{s \in S} P_s \times B_s \ (17).$$

For a selected component or event i, the failure probability of i is set to one. The total importance under this forced-failure condition is calculated by summing the scenario-level probability-weighted burdens after the forced-failure update. The burden-based RAW is the ratio of this forced-failure total importance to the baseline total importance. This form follows the interpretation of conventional RAW, but the risk metric is the expected core-water-level burden rather than the core damage frequency alone [1, 2]. The measure is also consistent with DPSA practice because the scenario probability and the transient response are evaluated at the same scenario level [3, 4].

The baseline total importance is 5.38E-10. Under the forced-failure condition for the HPSI signal delay, the total importance is 5.29E-9 and the burden-based RAW is 9.78. Under the forced-failure condition for the HPSI pump, the total importance is 2.47E-7 and the burden-based RAW is 459. The pump RAW is therefore about 46.9 times larger than the signal RAW.

The result indicates that the HPSI pump is more important than the HPSI signal delay for the present case. The HPSI signal delay affects the timing of injection initiation. Its failure condition can shift the start of mitigation and can reduce the available time margin. However, if the pump and downstream flow path remain available, injection can still occur after the signal is generated. The HPSI pump failure has a different effect. It removes or strongly degrades the sustained injection capability needed to recover the core water level. For the 0.0039 m^2 break and 10 h mission time used here, this direct loss of injection capability produces a much larger increase in the probability-weighted core-water-level burden.

The magnitude of the pump RAW should be interpreted as a case-specific result. It depends on the credited systems, the break size, the mission time, the 3,600 s bin width, the 20% CD criterion, and the selected burden weights. It does not mean that the HPSI pump will dominate every accident class. It means that, within this model boundary, forcing the HPSI pump to fail increases the expected burden by a factor of 459 relative to the baseline. This makes the pump the controlling contributor among the compared HPSI variables.

The result also shows why a burden-based importance measure is useful. A binary CD indicator can rank components by their effect on endpoint occurrence. The proposed measure adds information on how deeply the core water level moves toward or beyond the criterion. This is important for DPSA because event timing and plant response can change the severity of a sequence even when the endpoint category is unchanged [3-7]. In the present analysis, the pump-dominant ranking follows from both probability and thermal-hydraulic consequence: the pump failure has a larger effect on sustained core water level degradation than the signal delay.

4. CONCLUSION AND FUTURE WORKS

This study applied a core-water-level burden-based importance measure to a MARS-KS based DPSA case. The analysis credited only HPSI and SIT, used a break size of 0.0039 m^2, applied a 10 h mission time, and discretized all time-dependent equipment variables from 0 to 36,000 s with a 3,600 s interval. Core damage was defined as a core water level of 20% or lower. The scenario burden was calculated with an exponential function of the normalized distance from the 20% criterion. The scenario importance was calculated as the product of scenario probability and burden, and the total importance was calculated as the sum over all scenarios.

The baseline importance was 5.38E-10. The HPSI signal delay produced a forced-failure importance of 5.29E-9 and a burden-based RAW of 9.78. The HPSI pump produced a forced-failure importance of 2.47E-7 and a burden-based RAW of 459. The HPSI pump is therefore the dominant contributor in this case. Its RAW is about 46.9 times larger than the signal-delay RAW. This result supports the conclusion that sustained HPSI pump availability has a stronger effect on the probability-weighted core-water-level burden than HPSI signal timing under the present assumptions.

The main value of the proposed metric is that it retains the meaning of RAW while using a thermal-hydraulic burden instead of a binary endpoint. A component with a high burden-based RAW is not only associated with a higher probability of an undesirable endpoint. It is associated with a larger probability-weighted degradation of the selected safety margin. This makes the measure suitable for DPSA applications where the analyst needs to rank components using both scenario likelihood and time-dependent plant response [3-7].

Several extensions are needed before using the metric for broader decision making. First, the case should be repeated for additional break sizes, initiating events, and mission times. Second, the sensitivity of the ranking to the burden weights and the 20% CD criterion should be quantified. Third, the credited safety systems should be expanded beyond HPSI and SIT. Fourth, the burden should be extended to multiple variables, including pressure, safety injection flow, and operator action timing. Fifth, the burden-based ranking should be compared with conventional RAW, RRW, FV, and Birnbaum rankings to identify cases where the dynamic response changes the importance order [1, 2]. These steps will clarify whether the pump-dominant result is specific to this case or remains stable across a wider DPSA model.

Acknowledgements

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. RS-2022-00143695 and RS-2022-00144042).

References

[1] M. van der Borst and H. Schoonakker. "An overview of PSA importance measures", Reliability Engineering & System Safety, 72(3), pp. 241-245, (2001).

[2] M. C. Cheok, G. W. Parry, and R. R. Sherry. "Use of importance measures in risk-informed regulatory applications", Reliability Engineering & System Safety, 60(3), pp. 213-226, (1998).

[3] P.-E. Labeau, C. Smidts, and S. Swaminathan. "Dynamic reliability: towards an integrated platform for probabilistic risk assessment", Reliability Engineering & System Safety, 68(3), pp. 219-254, (2000).

[4] T. Aldemir. "A survey of dynamic methodologies for probabilistic safety assessment of nuclear power plants", Annals of Nuclear Energy, 52, pp. 113-124, (2013).

[5] H. Lee, T. Kim, and G. Heo. "Application of Dynamic Probabilistic Safety Assessment Approach for Accident Sequence Precursor Analysis: Case Study for Steam Generator Tube Rupture", Nuclear Engineering and Technology, 49(2), pp. 306-312, (2017).

[6] X. Zheng, H. Tamaki, T. Sugiyama, and Y. Maruyama. "Dynamic probabilistic risk assessment of nuclear power plants using multi-fidelity simulations", Reliability Engineering & System Safety, 223, 108503, (2022).

[7] J. W. Park and S. J. Lee. "Simulation Optimization Framework for Dynamic Probabilistic Safety Assessment", Reliability Engineering & System Safety, 220, 108316, (2022).

[8] N. H. Hoang, Y. K. Kwack, S. H. Bae, Y. S. Kim, and S. K. Sim. "Improvement of MARS-KS sub-channel module using CTF code", Nuclear Engineering and Design, 358, 110431, (2020).

[9] G. Heo, S. Baek, D. Kwon, H. Kim, and J. Park. "Recent research towards integrated deterministic-probabilistic safety assessment in Korea", Nuclear Engineering and Technology, 53(11), pp. 3465-3473, (2021).