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Importance Analysis of In-Service Testing Components for Ulchin Unit 3 Using Risk-Informed In-Service Testing Approach

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Abstract

We performed an importance analysis of In-Service Testing (IST) components for Ulchin Unit 3 using the integrated evaluation method for categorizing component safety significance developed in this study. The developed method is basically aimed at having a PSA expert perform an importance analysis using PSA and its related information. The importance analysis using the developed method is initiated by ranking the component importance using quantitative PSA information. The importance analysis of the IST components not modeled in the PSA is performed through the engineering judgment, based on the expertise of PSA, and the quantitative and qualitative information for the IST components. The PSA scope for importance analysis includes not only Level 1 and 2 internal PSA but also Level 1 external and shutdown/low power operation PSA. The importance analysis results of valves show that 167 (26.55%) of the 629 IST valves are HSSCs and 462 (73.45%) are LSSCs. Those of pumps also show that 28 (70%)of the 40 IST pumps are HSSCs and 12 (30%) are LSSCs.

Key Words : in-service testing, risk-informed, importance analysis, probabilistic safety assessment.

1. Introduction

The risk-informed in-service testing (RI-IST) method is to classify IST components and to apply different test requirements to them according to their contributions to the safety of a nuclear power plant (NPP) using the probabilistic safety assessment (PSA) method as the means of quantitative evaluation and the deterministic method as the means of qualitative safety evaluation [1, 2]. The RI-IST method includes current non-IST components. Until recently, the same IST requirements of the ASME code have been applied to the IST components of a NPP without the consideration of their contributions to its safety. However, the PSA results of NPPs performed to date have shown that only a small fraction of IST components are significant to the safety of a NPP. The USA ASME has had an interest in applying a PSA technique to the IST since 1992. The RI-IST related documents, ASME code case 3 [2] and regulatory guides [1, 3], were published in 1998. The application of RI-IST to the Comanche Peak NPP, recently endorsed by NRC, decreased the number of IST components to be tested during the refueling operation from 1758 to 498 and much work supporting the IST [4,5]. However, the RI-IST in the US NPPs is not actively performed because the economic benefits by the application of the RI-IST are expected not to be great compared with those of the technical specific optimization or the risk-informed in-service inspection. Up to now, domestic studies on the state-of-art on the RI-IST and the importance analysis using Level 1 internal PSA have been performed [6, 7, 8].

The importance analysis in the RI-IST is to categorize safety related components as high safety significant components (HSSCs) and low safety significant components (LSSCs). In general, the importance analysis in the RI-IST is initiated as ranking the component importance using quantitative PSA information. Secondly, a series of sensitivity studies are performed on the components modeled in the PSA. The sensitivity studies may include the importance analyses using external, shutdown/low power operation, and Level 2 internal PSA. Also, they include the importance analyses on recovery actions, failure rate, truncation limit, etc.. Finally, an expert panel ranks the component importance based on the quantitative PSA information, qualitative safety information, and the review of history of the component operation [1,2]. The qualitative safety information is obtained through evaluating the safety significance of the components used in safety analysis report, technical specifications, emergency operation procedures, and etc. The review of the history of the component operation may include the estimation of component failure rate, the review of IST results or special test results such as safety evaluation results of motor operated valves, the review of maintenance history, etc.

The ASME code case 3 requires that an expert panel should be composed of at least 5 experts from the fields of operation and safety of NPP [2]. It also requires that the minimum experience of an expert panel be 50 man-years and each should have a general knowledge of PSA. A lot of documents should be prepared to justify the process of decision-making by an expert panel in the classification of the components. There is no domestic experience for the use of an expert panel in the RI-IST. NPPs will have difficulties in active application of the RI-IST if the requirements of an expert panel mentioned in ASME code case 3 are strictly applied. Domestic NPPs will have more difficulties in the organization and employment of an expert panel because the organization, management, and hierarchy of the employee at domestic NPPs are different from those at the US NPPs.

With those backgrounds mentioned above, we developed the integrated evaluation method for categorizing component safety significance that can be used in place of an expert panel. The development of the integrated evaluation method is basically aimed at having a PSA expert perform an importance analysis using a PSA and its related information. The other object of the development is to reduce the man-hours and time of performing the RI-IST. Figure 1 shows the overall process of this study using the developed method. The main differences between the developed method and the ASME method utilizing an expert panel are 1) whether an expert panel is utilized or not, and 2) whether the quantitative information of the failure mode for the components not modeled in PSA is used or not. The importance analysis using the developed method is initiated by ranking the

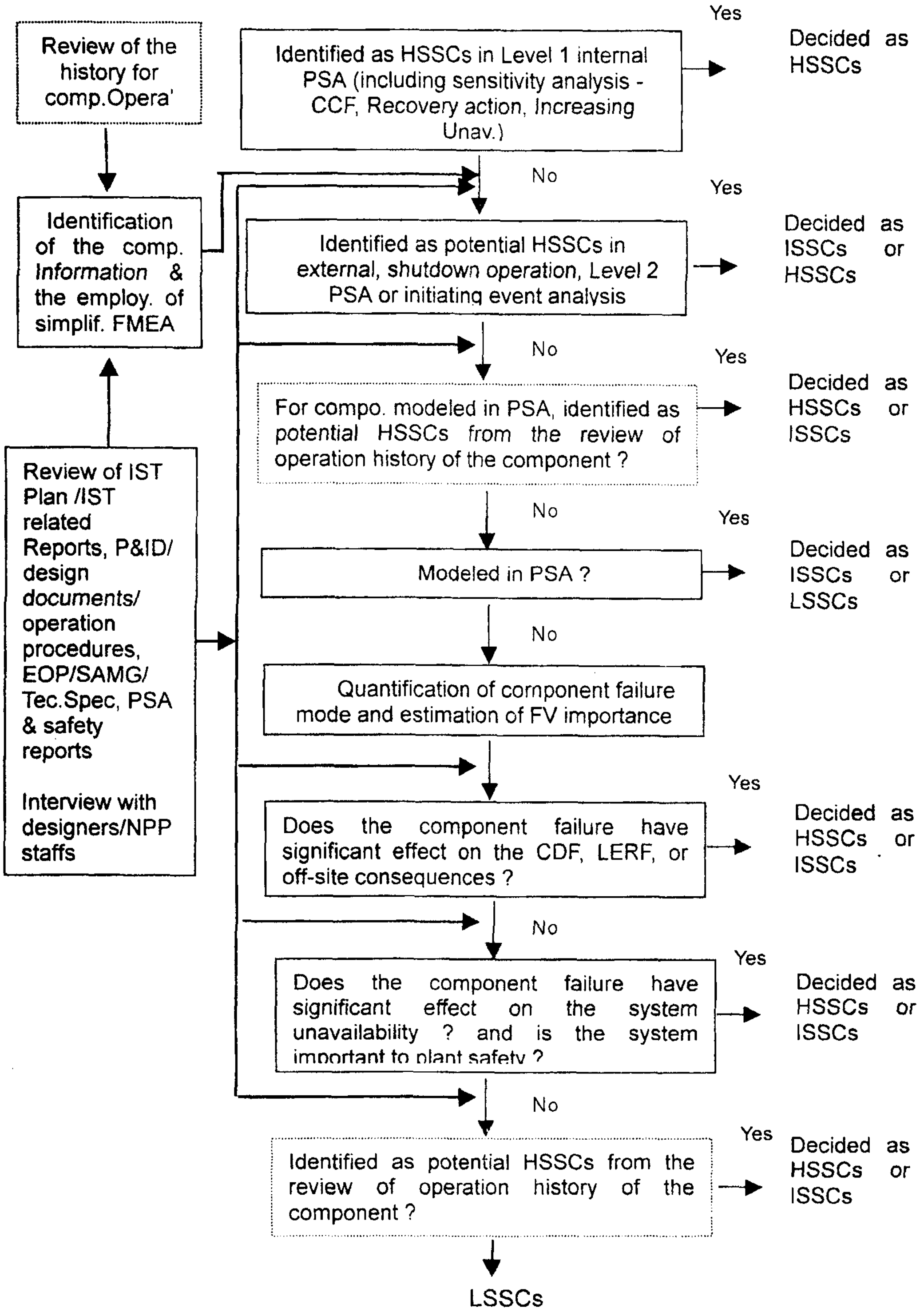

Fig. 1. Integrated Evaluation Procedure of Categaorizing Component Safety Significance

component importance using quantitative PSA information in the same way as the general RI-IST. For the components not modeled in the PSA, the simplified failure modes and effects analysis (FMEA) and the quantitative evaluation of the component failure mode are performed to them to get the quantitative information for categorizing the IST components. The final categorizations of the IST components not modeled in the PSA are performed through the engineering judgment, based on the expertise of PSA and the quantitative and qualitative information for the components.
Using the developed method, we categorized the IST components for Ulchin Unit 3 as HSSCs and LSSCs. In Section 2, the importance analysis method is presented. In Section 3, the importance analysis results are presented. In Section 4, conclusions are presented.

2. Importance Analysis Method

In Section 2.1, importance analysis method using a PSA is presented. In Section 2.2, integrated evaluation method, mainly focusing on the components not modeled in PSA, is described.

2.1. Importance Analysis Using a PSA

After reviewing previous studies on the RI-IST, we selected the importance measures, determined the ranking criteria for the selected importance measures and decided the items of sensitivity analysis to be used for this study.

2.1.1. Importance Measures and Ranking Criteria

We selected the Fussel-Vesely (FV) importance and the risk achievement worth (RAW) as the measures of risk importance for categorizing the IST components modeled in PSA for Ulchin Unit 3 [9, 10]. The importance measures recently used in most of the studies for the RI-IST were the FV importance and the RAW [11]. The risk reduction worth (RRW) was also used in some studies, but this can be represented as the FV importance. The FV importance and the RAW are defined as follows [10]:

$$\text{FV importance} = [R_o - R_i(-)] / R_o = 1 - Ri(-) / Ro = 1 - 1/RRW \qquad (1)$$

$$RAW = R_i(+) / R_o \qquad (2)$$

$$RRW = R_o / R_i(-) = 1/(1-FV) \qquad (3)$$

where R_o : basic risk,
$R_i(+)$: risk when basic event i fails
$R_i(-)$: risk when basic event i succeeds

The FV importance represents the fractional contribution of a component or system failure to the end state of interest such as system unavailability, core damage frequency (CDF), large early release frequency (LERF), etc. The increase of the component failure rate results in the increase of FV importance. However, there is no exact proportionality between the component failure rate and the FV importance value. The RAW is an appropriate measure for assessing the temporary change of when a component is out of service. Careful interpretation is required for the use of RAW since it may be unrealistic to assume that highly reliable components always fail.

The meaning of safety significance is different from that of risk significance. As represented in the meanings of the FV importance of equation 1 and of the RAW of equation 2, the identification of components safety significance using the FV importance and the RAW is to perform an importance analysis with respect to risk. The RG 1.175 [1] does not distinguish the meaning of safety significance from that of risk significance.

We used the same approach (RG 1.175) in classifying the component safety significance. The issues for the importance measures are addressed well in the papers of Fussel Vesely, Michal C. Cheok et al., and R. W. Young Blood [12, 13, 14]. In this paper, the issues for the importance measures were not discussed in detail because they are beyond of the purposes of this paper.

The criteria of the importance measures to categorize the IST components were determined mainly based on the FV importance. The criteria of the FV importance and the RAW used in this study are as follows:

- HSSCs (high safety significant components):
  - FV >0.005, or 0.005 > FV > 0.001 and RAW >2
- ISSCs (intermediate safety significant components):
  - 0.001 > FV >0.0001 and RAW >2
- LSSCs (low safety significant components):
  - FV < 0.005 and RAW < 2 or FV < 0.0001

2.1.2. Sensitivity Analyses

After reviewing the RG 1.175 [1], ASME code case 3 [2], and RG 1.174 [3], the items of the sensitivity analyses were decided as follows:

- Importance analysis without common cause failure (CCF) events

  Initial importance analysis results of IST components for Ulchin Unit 3 showed that the CCF events were the main contributors to the high fraction of the HSSCs. Therefore, the importance analysis without CCF events was performed to prevent the significance of single failure events from being low.
- Importance analysis without recovery errors

  Most recovery errors are connected to the basic events of component failure with "AND" logic of Boolean Algebra [9, 15]. This "AND" logic decrease the FV importance value. This may distort the importance analysis results. Recovery errors for components in the Level 1 PSA for Ulchin Unit 3 were considered for only motor operated valves.
- Importance analysis using the upper bound (95%) of distribution as mean of failure probability for the ISSCs or LSSCs

  The importance measures for initially ranked ISSCs or LSSCs are recalculated using the upper bound of the mean of their failure rate. This approach will also meet the requirements on the data uncertainties and the use of increased failure rate mentioned in ASME code case 3 [2] and RG 1.174 [3].

In this study, the cutoff value of 1.0E-11 was used as the truncation limit. This cutoff value meets the criteria for the truncation limit mentioned in ASME code case 3 [2] and RG 1.174 [3]. The PSA scope for quantitative importance analysis in this study were the Level 1 internal and external and Level 2 (LERF) internal PSA for Ulchin Unit 3, and Low power/Shutdown operation internal PSA for Younggwang Unit 5&6. We also reviewed the initiating event analysis results of each PSA model. Sensitivity analyses were performed using only the Level 1 internal PSA model for Ulchin Unit 3.

2.1.3. Rules of Ranking the Component Importance

The importance analysis results for single failure and common cause failure events were separately addressed because of the uncertainties for the common cause failure events. We first performed a basic importance analysis of components using the Level 1 internal PSA model for Ulchin Unit 3. Secondly, we performed the sensitivity analyses on the CCF events and recovery errors. Thirdly, the failure rates for initially ranked ISSCs or LSSCs resulting from the basic importance analysis and the sensitivity analyses on the CCF events and the recovery errors were increased by 95% percentile of the failure rate and the importance measures were recalculated.

The rules of ranking the component importance are as follows:

1) Selection of the highest safety significant component group among the categorized safety significant component groups (HSSCs, ISSCs, or LSSCs) identified from the basic importance analysis and sensitivity analyses
2) Selection of the sources for the importance analysis as the following orders if the categorizations of component safety significance are the same:
   a. Basic importance analysis
   b. Importance analysis without CCF events
   c. Importance analysis without recovery errors
   d. Importance analysis using 95% percentile of the failure rate for the initially ranked LSSCs and ISSCs

After having finished the importance analysis using the Level 1 internal PSA model for Ulchin Unit 3, we identified the candidates for the HSSCs, which had not been identified in basic importance analysis and sensitivity analyses, from the importance analyses using Level 1 external, Level 2 internal (LERF), shutdown/low power operation PSA model, and the review of their initiating event analyses. The final categorization of identified potential HSSCs were performed after the review of the PSA logic (fault tree and event tree) and assumptions used for the development of PSA model.

2.2. Integrated Evaluation Method

The processes and criteria of the importance analysis using the integrated evaluation method are presented in detail in this Section.

2.2.1. Level 1 Internal PSA

The components identified as HSSCs (including sensitivity analyses) resulting from the importance analysis using Level 1 PSA and the sensitivity analyses were decided as HSSCs. The ranking of component importance using a PSA can be differently decided according to the use of different criteria for the importance measures, the approach to addressing the sensitivity analysis results, and the requirements for the application areas of importance analysis.

2.2.2. Failure Modes and Effects Analysis

For the components identified as ISSCs or LSSCs through the importance analysis using Level 1 internal PSA, the simplified Failure Modes and Effects Analysis (FMEA) is performed to make a sure that they cannot be categorized as HSSCs. For the components not modeled in PSA, the simplified FMEA is also performed to get the quantitative information for categorizing component safety significance. The process of performing the simplified FMEA is as follows:

- Identification of the basic information (normal position during operation, received safety signal, failure position, and etc.) for the components,
- Identification of component failure modes and evaluation of their effects from the viewpoint of the plant risk (system failures, initiating events, containment isolation failures, and off-site consequences),
- Identification of other components having the same function in case the component which is to be evaluated, fails,
- Identification of the critical failure mode and its effect assumed to have the most severe effect on the plant risk, and
- Documentation

While performing the simplified FMEA, we reviewed several documents relating to the IST and safety for a NPP and had the interviews with system designers and NPP staff. In this study, we did not review the history of the IST component operation for Ulchin Unit 3 because its operation experience is short.

2.2.3. Other PSA

The components identified as potential HSSCs resulting from the importance analyses using external, Level 2 internal, shutdown/low power operation PSA, or the initiating event analyses were finally categorized after performing the simplified FMEA and reviewing the assumptions, and success criteria of fault trees and event trees.

2.2.4. Operation History of the Component

Based on the RG 1.175 [1], ASME code case 3 [2] and RG 1.174 [3], the evaluation criteria are made. If the component failure causes the failures of other important components or systems, and the failures of the component correspond to one of the followings, the components are decided to be HSSCs or ISSCs:

- The failure rate of the component is high compared with that of other components or the performance capabilities (leakage rate, pumping force, etc.) of the component are low compared with those,
- The component failure significantly causes the degradation of the defenses for a human error or a CCF, or
- The component failure causes the introduction of a new CCF

These evaluation criteria are applied to the components identified as ISSCs or LSSCs resulting from the importance analysis using a PSA and the components not modeled in PSA. In this study, we did not review the history of the IST component operation for Ulchin Unit 3 because its operation experience is not much.

2.2.5. Quantification of Failure Mode and Qualitative Evaluation Criteria for the Components Not Modeled in PSA

After the employment of the simplified FMEA to the components not modeled in PSA, the identified failure mode of the component was quantified to get the quantitative information. The quantification is not performed for the components of which failures are assumed not to be occurred or to have negligible effects on the system unavailability, CDF, LERF or off-site consequences. The quantification of the component failure mode is performed with the assumption of IST not being performed for one year. The reason of making a conservative assumption for the IST interval is that 1) the history of component operation is not reviewed, and 2) the FV importance value obtained using equation 4 is not exact. If the failures of the components not modeled in PSA correspond to one of the bellows, the components were decided to be HSSCs or ISSCs:

- The component failure has a significant effect on the CDF, LERF, or Off-site consequences, or
- The component failure has a significant effect on the system unavailability, and the system is very important to the plants' safety.

2.2.6. Quantitative Evaluation Criteria for the Components Not Modeled in PSA

The quantitative evaluation criteria of the FV importance and the RAW for the components not modeled in PSA are estimated through identifying those for the system unavailability, initiating event frequency, or containment isolation failure frequency related to the component failure. The quantitative evaluation criterion of FV importance is obtained using the following equation:

$$X_{CRI}(i) = X(i)^{*}CRI \, / \, FV(X(i)) \qquad (4)$$

where, $X(i)$: system unavailability, initiating event frequency, or containment isolation failure frequency related to the failure of component i

$FV(X(i))$: FV importance for the system unavailability, initiating event frequency, or containment isolation failure frequency related to the failure of component i

$X_{CRI}(i)$: system unavailability, initiating event frequency, or containment isolation failure frequency, of which FV importance corresponds to CRI, related to the failure of component i

CRI: criteria of FV importance corresponding to HSSCs, ISSCs, or LSSCs (0.005, 0.001, or 0.0001), respectively

The FV importance of the component was estimated by the comparison of the quantification results of the component failure mode with the quantitative evaluation criterion. This approach is based on a proposition that the failure probability of a component is proportional to FV importance value. The FV importance value of the components obtained using equation 4 is not exact because equation 4 does not consider the failure logic structure of system, initiating event, or containment isolation. If the failure logic structure of system, initiating event, or containment isolation related to the component failure is parallel, the FV importance value of the component obtained using equation 4 is optimistic. If the failure logic structure is a series, it is conservative. In addition to the failure logic structures, other elements such as the operation time of the component, CCF, etc. affecting the component failure probability or frequency should be considered to estimate the exact FV importance of the components. However, it is not possible to exactly evaluate the FV importance of the components without new development of failure logic for the system, initiating event frequency, or containment isolation. Even though equation 4 has shortcomings in the evaluation of the FV importance, it can provide us with the quantitative basis for categorizing the components. For example, if the critical failure mode of the component "A" causes a initiating event "B", and the FV importance and the RAW of the initiating event "B" are very low compared with the criteria of those used in this study, we can decide the component "A" as LSSCs with the respect of component risk significance. If we perform a categorization of the component "A" without the use of equation 4, several documents relating to the component "A" should be reviewed and/or an expert panel have a discussion with each other to obtain the basis for which the component "A" is not significant to the plant risk.

The quantitative evaluation criteria for some components such as having significant effects on the off-site consequences cannot be directly obtained from equation 4. Based on the design documents, PSA results, severe accident management guideline (SAMG), and other safety reports, the component failure effects were qualitatively evaluated and the categorizations of component safety significance were performed with the consideration of the quantification result of the component failure mode.

2.2.7. Final Categorization of Components Not Modeled in PSA

The final decisions for categorizing the IST components not modeled in PSA were made by the engineering judgment, based on the expertise of PSA, the comprehensive applications of evaluation criteria mentioned above, the review of related documents, and the interview with the designers and NPP staff. As mentioned before, the FV importance obtained by equation 4 is not exact and the RAW cannot be directly obtained. Therefore, we considered the FV importance and the RAW as reference values for the categorization. Final categorization of the component safety significance was performed by engineering judgment, based on the review of design documents, P&ID, and safety related documents, the interview with designers and NPP staff, and the expertise of PSA.

3. Importance Analysis Results

Ulchin Unit 3 has 629 IST valves and 40 IST pumps [17]. The number of IST valves modeled in Level 1 internal PSA for Ulchin Unit 3 is 195(31%) of total IST valves. This number is estimated from only valves being modeled in fault trees of Level 1 internal PSA. The actual number of IST valves modeled in PSA logic is 346(55%) if all the valves considered in the development of fault tree, in the estimation of initiating event frequency, and in Level 2 PSA logic are included. The number of IST pumps modeled in the Level 1 internal PSA for Ulchin Unit 3 is 28(70%).

3.1. Importance Analysis Results Using a PSA

The KIRAP code [16] was used in the basic importance analysis and sensitivity analyses. Tables 1 and 2 show the summary of importance analysis results for valves and pumps using Level 1 internal PSA, respectively. As shown in Table 1, 94 of the 195 IST valves are identified as HSSCs, 32 as ISSCs, and 34 as LSSCs. 6 non-IST valves are identified as above ISSCs. Table 2 shows that 10 of the 40 IST pumps are identified as HSSCs, 4 as ISSCs, and 14 as LSSCs. Only 1 non-IST pump is identified as HSSC. Tables 3 and 4 show the sensitivity analyses results on IST valves and pumps importance ranking. 30 new valves are identified as HSSCs through the sensitivity analysis. The candidates newly identified as HSSCs resulting from external, Level 2 internal, shutdown/low power operation PSA, and the initiating event analyses are 12 pumps and 36 valves.

3.2. Final Importance Analysis Results

Tables 5 and 6 show the final importance

Table 1. Summary of Importance Analysis Results for Valves

Category	Modeled IST valves -195	Non-IST valves
HSSCs	30[CV], 42[MO], 4[AO], 16[RV]	2[VV]
ISSCs	20[CV], 4[HO], 2[MO], 4[SO]	1[CV], 3[VV]
LSSCs	34[CV], 4[AO], 28[MO], 7[SO]	Not Applicable

AO: air operated valve, CV: check valve, MO: motor operated valve,
RV: safety/relief valve, HO: hydraulic operated valve, SO: solenoid operated valve, VV: manual valve, PV: pneumatic valve

Table 2. Summary of Importance Analysis Results for Pumps

Category	Modeled IST pumps - 28	Non-IST pumps
HSSCs	2[AF TP], 2[AF MP], 2[HS MP], 2[LS MP], 2[CS MP]	1 [FW MP]
ISSCs	2[SW MP], 2[CW MP]	
LSSCs	4 [CC MP], 2[CV MP], 4 [CV RP], 2[SW MP], 2[CW MP]	

TP: turbine operated pump, MP: motor operated pump, RP: reciprocating pump AF: auxiliary feedwater pump, HS: high pressure safety injection system, LS: low pressure safety injection system, CS: containment spray system, CW: essential chilled water system, CC: component cooling water system, CV: chemical and volume control system, SX: essential service water system

Table 3. Sensitivity Analysis Results on Importance Ranking of IST Valves

Category	Basic analysis	Without CCF events	Without recovery errors	Use the upper bound of distribution for initially ranked ISSCs or LSSCs
HSSCs	62	6	20	4
ISSCs	12	0	0	18
LSSCs	61	0	0	12
Sub Total	135	6	20	34

Table 4. Sensitivity Analysis Results on Importance Ranking of IST Pumps

Category	Basic Analysis	Without CCF events	Use the upper bound of distribution for initially ranked ISSCs or LSSCs
HSSCs	10	0	0
ISSCs	0	0	4
LSSCs	9	0	5
Sub Total	19	0	9

analysis results for IST valves and pumps according to the types of PSA, respectively. Additionally identified number of HSSCs for IST valves from external, Level 2, and shutdown/low power operation PSA is 17. That from the valves not modeled in PSA is 8. However, in the case of IST pumps, we did not additionally identify HSSCs from other PSA. Table 5 shows that 117(18.6%) of the 629 IST valves are HSSCs, 50(7.95%) are ISSCs, and 462(73.45%) are LSSCs. Table 6 shows that 10(25%) of the 40 IST pumps are HSSCs, 18(45%) are ISSCs, and 12(30%) are LSSCs. If we classify the components as HSSCs and LSSCs, 167(26.55%) of the 629 IST valves and 28(70%) of the 40 IST pumps are HSSCs, respectively. Table 7 shows the comparison of importance analysis results among Ulchin Unit 3 and other NPPs [3]. All NPPs except Ulchin Unit 3 in Table 7 employed the expert panel in the final categorization of component safety

Table 5. Summary of Final Importance Analysis Results for IST Valves

IST Valves	Internal PSA	External PSA	Level 2 PSA	SD/LP PSA	Valves not modeled in PSA
HSSCs	92	2	8	7	8
ISSCs	30	0	2	4	14
LSSCs	67	0	0	0	395
Sub Total	189	2	10	11	417

Table 6. Summary of Final Importance Analysis Results for IST Pumps

IST Pumps	Internal PSA	External PSA	Level 2 PSA	SD/LP PSA	Pumps not modeled in PSA
HSSCs	10	0	0	0	0
ISSCs	8	0	0	4	6
LSSCs	6	0		0	6
Sub Total	24	0		4	12

Table 7. Comparison of Importance Analysis Results Among Ulchin Unit 3 and Other NPPs

	ST Pumps			IST Valves		
	HSSCs	LSSCs	% of HSSCs	HSSCs	LSSCs	% of HSSCs
Ulchin Unit 3	28	12	70%	167	462	26.55%
Palo Verde	18	6	69%	137	369	27%
Comanche Peak 1	21	12	63.6%	144	537	23.26%
San Onofre 2	18	10	64.28%	85	455	15.74%
South Texas	24	12	66.67%	141	423	25%

significance. In Table 7, the percentages of HSSCs to total IST components for Ulchin Unit 3 are similar to those of the Palo Verde NPP. However, the percentages of HSSCs to total IST valves for both of the NPPs are slightly higher than those for other NPPs. The high fraction of HSSCs for Ulchin Unit 3 may be mainly caused by the relatively conservative approach of component importance ranking and the differences of NPP design and PSA characteristics.

4. Conclusions

In this paper, we performed an importance analysis of the IST components for Ulchin Unit 3 using the integrated evaluation method of categorizing component safety significance developed in this study. The importance analysis using the developed method is initiated by ranking the component importance using quantitative PSA information. The final categorization of the IST components not modeled in the PSA is performed through the engineering judgment, based on the expertise of PSA, the quantitative and qualitative information of the component. After reviewing the previous research results on the risk-informed IST, we determined the ranking criteria for the selected importance measures and decided on the items of the sensitivity analyses using a PSA. The PSA scope of the quantitative importance analysis includes not only Level 1and2 internal PSA but also external and shutdown/low power operation PSA.

The importance analysis results using a PSA shows that 122 of the 195 valves modeled in Level 1 PSA are HSSCs and 73 are LSSCs. For the IST pumps modeled in Level 1 PSA, importance analysis results shows that 14 of 28 pumps are HSSCs and 14 are LSSCs. 30 new HSSCs were identified through the sensitivity analyses on the IST valves. The final importance analysis results of valves show that 167 (26.55%) of the 629 IST valves are HSSCs and 462 (73.45%) are LSSCs. The final importance analysis results of the pumps also show that 28 (70%)of the 40 IST pumps are HSSCs and 12 (30%) are LSSCs. The percentage of HSSCs to total IST components for Ulchin Unit 3 is similar to that for the Palo Verde NPP. The main design features of Ulchin Unit 3 are the same as those of Palo Verde NPP. The percentages of HSSCs to total IST valves for both NPPs are slightly higher than those for other NPPs. All NPPs except Ulchin Unit 3 employed the expert panel in the final categorization of component safety significance.

As the importance analysis results of the IST components using the developed method for Ulchin Unit 3 are almost the same to those using an expert panel for Palo Verde NPP, we can conclude that the developed method can be used in place of an expert panel in the RI-IST for Ulchin Unit 3. However, the direct applications of the developed method to other NPPs or fields may have some difficulty in obtaining reasonable importance analysis results in case of; 1) importance analysis without the reviews of RI-IST related documents or the interviews with the engineers relating to the IST components, 2) categorization of the components using only equation 4 without the considerations of shortcomings of it, 3) use of the same approaches to categorization of the components employed in this study without the reviews of the requirements and safety issues for the application fields of importance analysis. As future works, a review of the operation history for the components is needed to complete the categorization of the IST components for Ulchin Unit 3. Also, the studies on the actual application of the developed method to the optimization of IST requirements (MOV, check valves, etc.) are further needed to obtain the insight for its improvement.

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