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A Pilot Study of RI-IST Applications to IST Check Valves for Ulchin Unit 3

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ABSTRACT

We performed a pilot study of the risk-informed inservice testing (RI-IST) applications to the IST check valves for Ulchin Unit 3 to optimize their test interval. Ulchin Unit 3 is a pressurized water reactor in Korea. It has four reactor coolant pumps and two steam generators. It has 209 IST check valves. First, we classified them into three categories: high safety significant components (HSSCs), intermediate safety significant components (ISSCs), and low safety significant components (LSSCs) using quantitative and qualitative information for their safety significance to Ulchin Unit 3. Secondly, we performed the risk analysis on the relaxation of the test intervals for the IST check valves classified as being of relatively low importance to the safety of Ulchin Unit 3 to identify the maximum increasable test interval for them. Finally, we estimated the testing number resulting from the changes of test interval. The categorization results of the IST check valves are that the number of the HSSCs is 24(11.48%), the number of ISSCs is 40 (19.14%), and the number of LSSCs is 145(69.38%). Within the acceptable range of risk change, the current test interval of ISSCs2 can be increased by up to 6 times and that of LSSCs can be increased by up to 40 times. The changes of the previous categorization results of the IST check valves are identified as the most important constraint for the increase of test interval. The testing number of the IST check valves to be performed during 6 refueling outage times can be reduced from 7692 to 1333 (82.7%)

KEY WORDS: Inservice Testing, Risk-Informed, Check Valve, Importance Analysis, Categorization, Optimization of Test Interval

1. INTRODUCTION

The risk-informed in-service testing (RI-IST) approach categorizes the components and applies different testing requirements to them according to their contributions to the safety of a nuclear power plant (NPP) [1, 2, 3]. The classification of components in the RI-IST is initiated by ranking the component importance using quantitative probabilistic safety assessment (PSA) information. A NPP expert panel finally ranks the component importance based on the quantitative PSA information, qualitative safety evaluation, and the history of component operation, etc. [1,2]. After the categorization works are done, the IST programs for the categorized components are developed and implemented. In general, the objective of the IST program for high safety significant components (HSSCs) is to predict the failure or to identify the trend of performance degradation of them. That of low safety significant components (LSSCs) is to identify the operability readiness of them [2].

Since 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 ASME has had an interest in applying a PSA technique to the IST [4]. The RI-IST related documents such as regulatory guides [1] and ASME code case 3 [3] were published in 1998. The implementation of the RI-IST to Korean NPPs is not actively performed up to now. However, the interests on the RI-IST have been growing since several studies have been made; the pilot studies on the categorization of IST components [4, 5, 6], the study on the optimization of motor operated valve (MOV) testing requirements relating to the periodic safety evaluation of MOV [7], and the studies on the optimization of test requirements for IST valves at some NPPs [8, 9].

In this paper, we have optimized the test interval of the IST check valves, of which their number is the highest among the IST valves of Ulchin Unit 3, using the RI-IST approach. We categorized the IST check valves for Ulchin Unit 3 and performed the risk analysis on the relaxation of test intervals for the IST check valves classified as being of relatively low importance to the safety of Ulchin Unit 3 to identify the maximum increasable test interval for them. Ulchin Unit 3 is a pressurized water reactor in Korea. It has four reactor coolant pumps and two steam generators. In Section 2, the categorization method of check valve safety significance and the evaluation method of unavailability of check valves on the change of test interval are presented. In Section 3, the categorization results of the IST check valve safety significance and the identified maximum increasable test intervals are presented. Finally, conclusions are presented in Section 4.

2. METHODOLOGY

2.1 Categorization of check valves

Figure 1 shows the categorization procedure for the IST check valves of Ulchin Unit 3 performed in this study [5, 6]. We did not perform the tasks shown in the dotted-line box of Figure 1 because the operation experience of Ulchin Unit 3 is not enough for this study. We classified the check valve into three categories according to the Fussel-Vesely (FV) importance and the risk achievement worth (RAW): high safety significant components (HSSCs), intermediate safety significant components (ISSCs), and low safety significant components (LSSCs). ISSCs are further classified into ISSCs1 (RAW>2 and 0.005 > FV > 0.001) and ISSCs 2 (RAW>2 and FV < 0.001). Table 1 shows the criteria for the categorization of component safety significance using PSA. In the final categorization of the check valve safety significance, we also used the qualitative information in addition to the quantitative information for the IST check valves. The FV importance and the RAW are defined as follows [10]:

$$\text{FV importance} = [R_o - R_i(-)] / R_o = 1 - R_i(-)/R_o \quad (1)$$

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

where, R_o : basic risk,

$R_i(+)$: risk when basic event *i* fails,

$R_i(-)$: risk when basic event *i* succeeds

Table 1. Criteria for the categorization of check valve safety significance using PSA

Categorized IST check valves	Ranges of importance value	
	FV importance	RAW
HSSCs	FV{CDF} or FV{LERF} > .005	All check valves
ISSCs	FV{CDF} and FV{LERF} < .005	RAW{CDF} or RAW{LERF} > 2.0
LSSCs	FV{CDF} and FV{LERF} < .005 or Truncated check valves	RAW{CDF} and RAW{LERF} < 2.0 or Truncated check valves

For the IST check valves modeled in PSA for Ulchin Unit 3, at first, we classified them by using the FV importance and the RAW for core damage frequency (CDF) and large early release frequency (LERF). Secondly, we performed sensitivity analyses using Level 1 PSA model. We also considered importance analysis results of Level 1 shutdown/low power operation PSA and external event PSA, and reviewed the initiating event analysis results of each operation mode [11, 12]. Thirdly, we performed the simplified failure modes and effects analysis (FMEA) and qualitative evaluation for the IST check valves identified as ISSCs and LSSCs to make sure that they are not classified as HSSCs. The qualitative evaluation was performed through the review of piping and instrumentation diagram (P&ID), safety reports, etc. and interviews with plant staff and design engineers. Final categorization of the IST check valves modeled in PSA was performed by engineering judgments, based on quantitative PSA information and qualitative evaluation results. Based on the references [3, 13, 14], the items of sensitivity analyses were decided as follows:

- Common cause failure (CCF) events
  - Importance analysis without CCF events: The CCF events may mask the significance of single failure events.
  - Importance analysis using CCF probabilities increased by 10 times: The CCF probabilities used in Ulchin Unit 3 PSA are identified as low comparing them with those of other PSA related reports.
- Failure rate: importance analysis using the upper bound (95%) of distribution as a mean of failure probability for the ISSCs and LSSCs

For the IST check valves not modeled in PSA for Ulchin Unit 3, we categorized them through the engineering judgments, based on the expertise of PSA and the quantitative and qualitative information for the check valves. The quantitative information for the check valves not modeled in PSA was obtained through the employment of the simplified FMEA and the quantification of their critical failure mode. The qualitative information was obtained through the review of safety related documents and interviews with design engineers and NPP staff relating to the check valves. We estimated the FV importance and the RAW for the IST check valves not modeled in PSA through identifying those for system unavailability, initiating event frequency, or containment isolation failure frequency related to the check valve failure. The FV importance for the IST check valves not modeled in PSA was obtained by applying the following procedures:

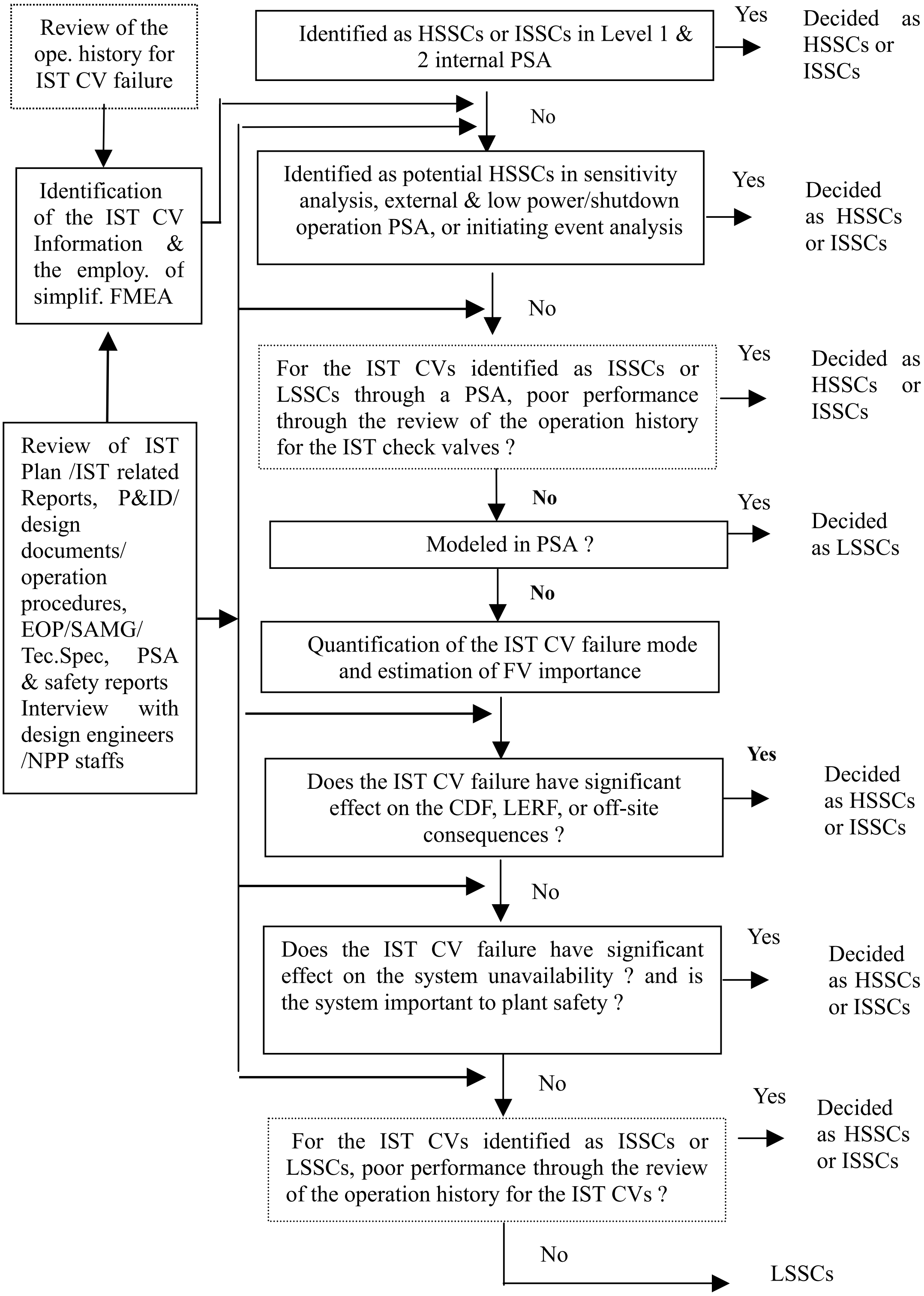

Figure 1. Integrated categorization procedure of the IST check valves

- Identification of the critical failure mode and its effect assumed to have the severest effect on plant risk
- Quantification of the critical failure mode and identification of the system, initiating event etc. related to the check valve failure
- Estimation of the FV importance of the check valve through the comparison of quantification results of the check valve failure mode with the quantitative evaluation criterion

Quantitative evaluation criterion of FV importance is as follows:

$$X_{CRI}(\boldsymbol{i})=X(\boldsymbol{i})*CRI/\ FV(X(\boldsymbol{i}\ ) \quad (3)$$

where, $X_{CRI}(\boldsymbol{i})$: system unavailability, initiating event frequency, or containment isolation failure frequency, of which FV importance corresponds to CRI, related to the failure of the IST check valve ***i***

$X(\boldsymbol{i})$: system unavailability, initiating event frequency, or containment isolation failure frequency related to the failure of the IST check valve ***i***

CRI: criteria of FV importance corresponding to HSSCs (0.005)

$FV(X(\boldsymbol{i}))$: FV importance for the system unavailability, initiating event frequency, or containment isolation failure frequency related to the failure of the IST check valve ***i***

The FV importance of the check valve was estimated by the comparison of the quantification results of the check valve failure mode with the quantitative evaluation criterion. This approach is based on the assumption that the failure probability of a check valve is proportional to FV importance value. The FV importance value of the check valve obtained using equation (3) is not exact because equation (3) 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 check valve failure is parallel, the FV importance value of the check valve obtained using equation (3) 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 check valve, CCF, etc. affecting the check valve failure probability or frequency should be considered to estimate the exact FV importance of the check valves. However, it is not possible to evaluate exactly the FV importance of the check valves without developing the new failure logic for the system, initiating event, or containment isolation. Even though equation (3) has shortcomings in the evaluation of the FV importance, it can provide us with the quantitative basis for categorizing the check valves. For example, if the critical failure mode of the check valve "***C***" causes a initiating event "***I***", and the FV importance and the RAW of the initiating event "***I***" are low compared with the criteria of those used in this study, we can easily obtain the basis for which the check valve "***C***" is not significant to the plant risk.

As the FV importance obtained by equation (3) is not exact and the RAW cannot be directly obtained, we considered the estimated FV importance and the RAW as reference values for the categorization. The final decisions for categorizing the IST check valves not modeled in PSA were made by engineering judgments, based on the expertise of PSA, the review of related documents, and interviews with the design engineers and NPP staff.

2.2 Estimation of unavailability on the change of test interval

In the case that the failure modes of the IST check valves modeled in fault trees which are demand or standby failures, the unavailability, q_T, of them can be expressed as the following equation:

$$q_T = q_D + \lambda * T/2 \quad (4)$$

where, q_D: unavailability caused by demand failure

λ: standby failure rate,

T : test interval

In Ulchin Unit 3, demand failure or standby failure is only considered as the failure mode of a check valve. As the operation experience of Ulchin Unit 3 is not enough for this study, generic failure data [15, 16] were used for the estimation of demand failure probability, q_D, and standby failure rate, λ. According to reference [17], we assumed that the unavailability of a check valve is proportional to the increase of the test interval of it. In other words, if the test interval of a check valve is increased by 3 times, the unavailability of it caused by any failure mode is increased by 3 times. Following assumptions were made for the quantification of the IST check valve unavailability varied with the increase of test intervals:

- As the test interval of a check valve is increased, the unavailability of it resulting from the demand or the standby failure is also increased.
- Standby failure rate λ is constant
- Complete renewal is assumed at the end of test interval.
- No aging effects are considered.
- No surveillance test wear out is considered.

3. RESULTS

This section describes the categorization results of the IST check valves, the quantification results and the number of tests after the changes of test intervals. Ulchin Unit 3 has 209 IST check valves [18]. 84 of them are modeled in Level 1&2 internal PSA for Ulchin Unit 3. Table 2 shows the final categorization results of check valve importance. As shown in Table 2, the percentage of HSSCs is 11.48% (24), that of ISSCs is 19.14% (40), and that of LSSCs is 69.38% (145). We could not find additional HSSCs or ISSCs from low power/shutdown PSA and external event PSA. If we adopt two classification categories, HSSCs and LSSCs, the percentage of HSSCs is 30.62% (64). Table 3 shows the comparison of categorization results of check valves between Ulchin 3 and ASCO NPP [9]. The percentage of HSSCs for Ulchin Unit 3 is higher than that for ASCO NPP. It is expected that the high percentage of HSSCs for Ulchin Unit 3 would be mainly caused by the application of different criteria to the categorization of IST check valves. The categorization approach used in this study is assumed to be rather conservative compared with that of the previous studies [8, 9].

Table 2. Final categorization results of the IST check valves for Ulchin Unit 3

	Level 1	Level 2	Sensitivity (Level 1)	Low power/ shutdown	External	Not modeled in PSA
HSSCs : 24	14	10	0	0	0	0
ISSCs1: 10	0	8	2	0	0	0
ISSCs2: 30	24	0	0	0	0	6
LSSCs: 145	26	0	0	0	0	119
Sub Total.– 209	64	18	2	0	0	125

Table 3. Comparison of categorization results of the IST check valves between Ulchin and ASCO

	Ulchin 3 NPP	ASCO NPP[9]
PSA scope	L1&2(internal), sensitivity, external, Low power/SD	L1(internal), L2(internal) – qualitative, sensitivity
Utilization of an expert panel	No, Use of the developed method	Yes
Modeling ratio	84 of 209 (40%)	115 of 164(70.12%)
No of HSSCs	64(30.62%)	37(22.56%)

We performed the risk analysis on the relaxation of test intervals for the check valves identified as ISSCs2 and LSSCs to identify the maximum increasable test intervals for them. The risk analysis and the identification of the maximum increasable test intervals were performed based on the following assumptions:

- Failure rates of check valves are increased by the increase of the test interval
- No changes on the categorization results of check valves is allowed after the increase of the test interval
- Acceptable ranges of risk changes are:
  - •CDF (CDF after change of test interval – CDF before change of test interval) < 1.0E-5 and
  - •LERF (LERF after change of test interval – LERF before change of test interval) < 1.0E-6
- A limit of maximum increasable test interval is 10 years
- Test intervals for several kinds of tests of each IST check valve can be relaxed
- In case several kinds of tests for one IST check valve are performed and the increases of their test intervals are different from each other, the highest failure rates among the ones estimated from the increase of test intervals was used for the evaluation of risk

The evaluation results of the risk based on the assumptions above show that the maximum increasable test interval was identified as follows:

- No changes of test intervals for check valves identified as HSSCs/ISSCs1.
- Current test intervals of check valves identified as ISSCs2 can be increased by up to 6 times.
- Current test intervals of check valves identified as LSSCs can be increased by up to 40 times.

Table 4 shows the number of tests after the increase of test intervals for the check valves of Ulchin Unit 3. The number of tests after the increase of test intervals during 6 refueling outage times (9 years) can be reduced from 7692 to 1333(82.7%). The operability of some IST check valves can be tested during the test of IST pumps. In this case, the number of tests to be performed during 6 refueling outage times (9 years) can be also reduced from 3612 to 494(86.3%). The changes of the previous categorization results of the IST check valves are identified as the most important constraint for the increase of test intervals.

Table 4. Number of tests after the increase of test interval for the IST check valves of Ulchin Unit 3

Type of Tests	Testing Frequency	No. of valves	No. of Tests during 6 refueling outage times	In case of consideration of pump tests
Full Stroke Test	3 mon.	6	96 (4500)	0(2592)
	18 mon.	54	324(420)	108(240)
	108 mon.	135	135(0)	94(0)
	Sub Total		555(4920)	202(2832)
Partial Stroke Test	3 mon.	2	72(144)	72(144)
Reverse Flow Test	3 mon.	10	360 (2232)	144(360)
	18 mon.	16	96(132)	0(108)
	108 mon.	58	58(0)	19(0)
	Sub Total		514(2364)	163(468)
Leakage Rate Test	18 mon.	16	96(204)	0(108)
	108 mon.	58	58(0)	19(0)
	Sub Total		154(204)	19(108)
Dis-assembly and inspect.	36 mon.	2	6(42)	6(42)
	72 mon.	16	24(18)	24(18)
	108 mon.	8	8(0)	8(0)
	Sub Total		38(60)	38(60)
No. of Total Tests			1333(7692)	494(3612)

( ): based on the current test interval

4. CONCLUSIONS

We performed a pilot study of the RI-IST applications to the IST check valves for Ulchin Unit 3 to optimize the test interval for them. At first, we classified the IST check valves into HSSCs, ISSCs, and LSSCs using quantitative and qualitative information for their safety significance to Ulchin Unit 3. Secondly, we performed the risk analysis on the relaxation of test intervals for the IST check valves classified as being of relatively low importance to the safety of Ulchin Unit 3 to identify the maximum increasable test interval for them. Finally, we estimated the testing number resulting from the changes of test intervals. For the IST check valves modeled in a PSA, we used the FV importance and the RAW for CDF and LERF as risk importance measures for categorization. Qualitative evaluation for categorization was also performed. For the IST check valves not modeled in the PSA, we categorized the IST check valves through engineering judgments, based on the expertise of PSA and the quantitative and qualitative information for the IST check valves. The quantitative information for the check valves not modeled in PSA was obtained through the employment of the simplified FMEA and the quantification of their critical failure mode. The study results are as follows:

- The categorization results of the IST check valves; the number of the HSSCs is 24(11.48%), the ISSCs is 40

(19.14%), and the LSSCs is 145(69.38%)

- The maximum increasable test interval; 6 times of current test interval of ISSCs2 and 40 times of that of LSSCs
- The changes of the categorization results of the IST check valve are identified as the most important constraint for the increase of test intervals.
- The testing number of the IST check valves to be performed during 6 refueling outage time can be reduced from 7692 to 1333 (82.7%).
- This study results show that the categorization approach used in this study is rather conservative compared with that of previous studies [8, 9].

As this study does not fully satisfy the requirements of references [1, 19, 20, 21] relating to the RI-IST, the following studies are required for the actual optimizations of testing requirements for the IST check valves of Ulchin Unit 3:

- PSA update of Ulchin Unit 3
- Analysis and collection of the failure and performance data for the IST check valves
- Evaluation of testing effectiveness for the IST check valves
- Establishment and implementation of a monitoring program for the IST check valves

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