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Piping Failure Probability Assessments on Material Types, Temperatures and Leak Rates for a RI-ISI Program

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1. Introduction

Inservice Inspection (ISI) of piping elements is performed to identify pipe degradation mechanisms that may lead to leaks or ruptures. Risk-informed ISI (RI-ISI) is presently being applied as an alternative approach to the traditional method for establishing ISI requirements. The RI-ISI process is described in detail in WCAP-14572, Revision 1-NP-A [1].

As a part of this process, an assessment of the piping failure probabilities is made in order to support the segment risk ranking and change in risk tasks. The piping failure probability assessment is performed by using Structural Reliability and Risk Assessment (SRRA) software [2,3] developed specifically for piping RI-ISI. For each piping segment, information is gathered from various sources to provide the input for the SRRA model. The SRRA input is used to calculate the failure probabilities with and without the effects of inservice inspection for each piping segment. The calculated failure probabilities are then combined with the consequences of failure to develop the segment risk ranking and determine required inspection locations in accordance with the WCAP-14572, Revision 1-NP-A. One of the SRRA inputs is a type of piping material. It has 3 standard values: 304 stainless steel, 316 stainless steel, and carbon steel. To have a better understanding of effects of the types of piping material, a set of sensitivity assessment of SRRA software is performed.

2. Methods and Results

In this section a RI-ISI program is described briefly and then a set of sensitivity assessment of the piping materials of the SRRA software is described.

2.1 RI-ISI Program

The RI-ISI program consists of scope and segment definition, consequence evaluation and failure probability assessment, risk evaluation, expert panel categorization, and element/NDE selection as shown in Fig. 1.

Scope and segment definition is defining systems and segments in the RI-ISI program. In general, piping systems are included consistent with ISI, Probabilistic Safety Assessment (PSA), and Maintenance Rule. And piping segments are defined in order to be able to perform a systematic evaluation of the relative importance of the piping segments contained in each system. The approach used to define segments is based on the consequence evaluation. That is, piping sections in which failure would result in the same consequences are defined as a segment.

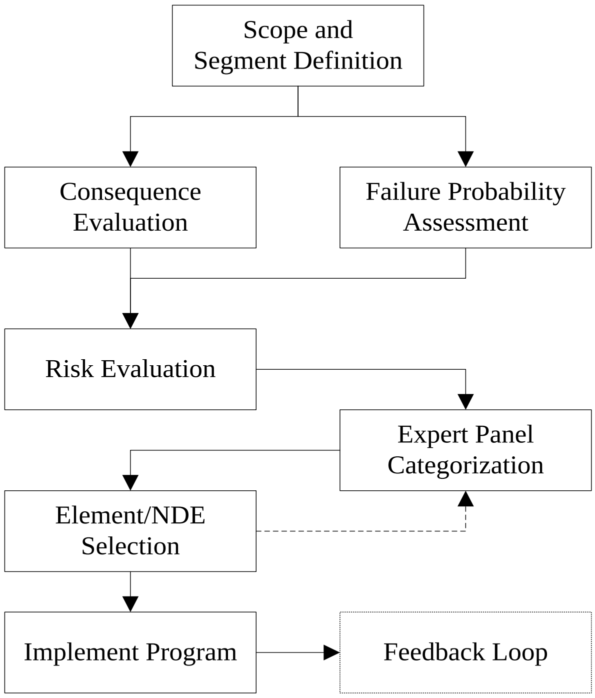


Fig. 1. Overall Risk-Informed ISI Process.

The consequence assessment associated with piping failure is made based primarily on the direct consequences. Direct consequences are defined as the loss of a system or an initiating event whereby the failed pipe causes a plant trip or other initiating event or reduces fluid flow of a system below that which is needed to respond to an initiating event. The indirect effects assessment is accomplished through an investigation of existing plant documentation on pipe breaks, flooding, and plant layout along with a focused plant walkthrough.

In general, each pipe segment in a RI-ISI program is evaluated for its failure potential. The piping failure probability assessment is performed by using SRRA software developed specifically for piping RI-ISI. The calculated failure probabilities at 40 years are then combined with the consequences of failure to develop the segment risk ranking and determine required inspection locations in accordance with the WCAP-14572, Revision 1-NP-A.

Core Damage Frequency/Probability (CDF/CDP) and Large Early Release Frequency/Probability (LERF/ LERP) are two major figures of merit. The piping CDF and LERF are determined to evaluate the risk significance of the RI-ISI program. As part of the RI-ISI program, it is necessary to quantify the conditional CDF and LERF, given that a pre-defined piping section fails.

To estimate the impact of piping failure on CDF and LERF, the piping failure consequences are simulated in a PRA model. Pipe failures are not normally included in the PRA model. Therefore, a surrogate component or group of components is defined so that its (their) failure(s) will simulate the postulated effects of the pipe segment's failure.

Once the surrogate components are identified, the PRA is re-quantified to calculate conditional CDF/CDP and LERF/LERP associated with each piping segment failure. These values can then be used in the RI-ISI program to calculate the segment CDF and LERF and risk importance measures. This risk information is presented to an Expert Panel along with other deterministic information. The Expert Panel then makes the final High Safety Significant (HSS) and Low Safety Significant (LSS) determination for each segment.

The identification of potential inspection locations within each HSS piping segment is obtained by a further review of the structural elements and postulated failure mechanisms. In general, the selection of inspection locations within each HSS piping segment is obtained by further review by a sub-panel, comprised of materials, ISI and NDE expertise.

2.2 Base SRRA Input Model

In developing of RI-ISI programs, there are material differences depending on the nuclear power plants between 304 stainless steel (304 St) and 316 stainless steel (316 St) on the segments of the same location. Therefore, the piping failure probability assessments of 304 St and 316 St using the SRRA software are compared. An example of a base SRRA input model is as shown in Table 1.

2.3 Sensitivity Assessment Results

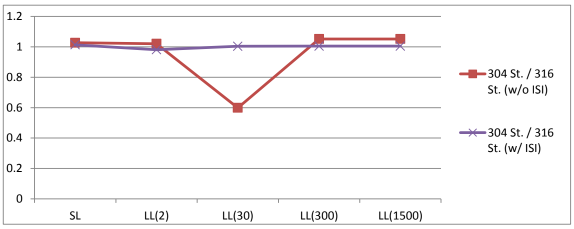
To find the effects of Nominal Pipe Size (NPS) changes, temperature at pipe weld and leak rates, the assessments are performed for NPS: 2, 5, 16; temperature at pipe weld: 150˚F, 350˚F, 550˚F; and leak rate: Small Leak(SL) and Large Leaks(LL: 2, 30, 300, 1500 gpm).

2.3.1. Results of NPS 2

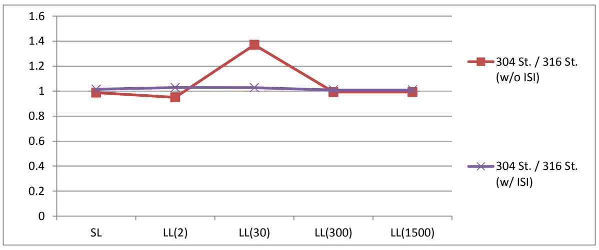
The results of the piping failure probability assessments for NPS 2 are shown in Fig. 2. For the temperature at pipe weld, 150˚F, the piping failure probability with

Table 1. Base SRRA Input Model

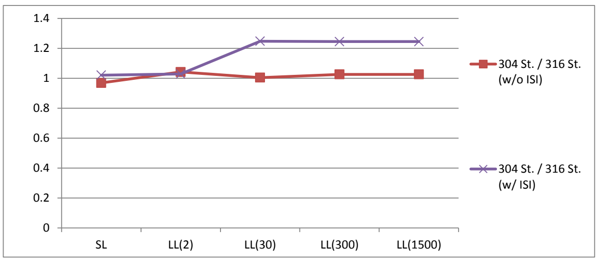
Input Description	Options	Set Value
1. Type of Piping Steel Material (2 Cases)	Carbon 304 St 316 St	304 St 316 St
2. Crack Inspection Interval	Medium	10
3. Crack Inspection Accuracy	Medium	0.24
4. Temperature at Pipe Weld	Medium	150 350 550
5. Nominal Pipe Size(3 Cases)	Small Medium Large	2 5 16
6. Thickness to O.D. Ratio	Normal	0.13
7. Normal Operating Pressure	Medium	1.3
8. Residual Stress Level	None	0.001
9. Initial Flaw Conditions	X-Ray NDE	1
10. DW and Thermal Stress Level	Medium	0.11
11. Stress Corrosion Potential	None	0.001
12. Material Wastage Potential	None	0.001
13. Vibratory Stress Range	None	0.001
14. Fatigue Stress Range	Medium	0.5
15. Low Cycle Fatigue Frequency	Medium	20
16. Design Limiting Stress	Medium	0.26



(a) For Temperature at Pipe Weld: 150˚F

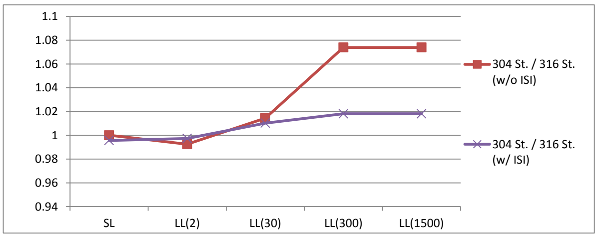


(b) For Temperature at Pipe Weld: 350˚F

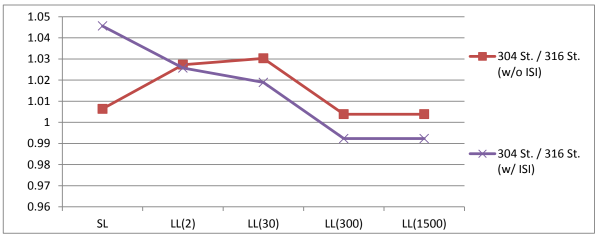


(c) For Temperature at Pipe Weld: 550˚F

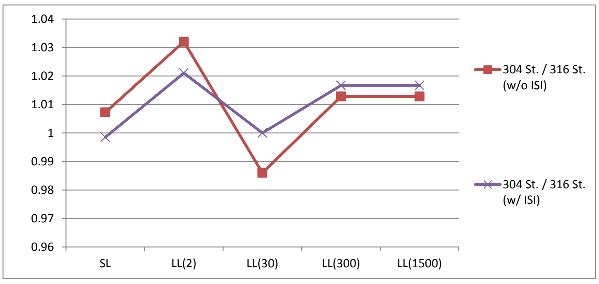
Fig. 2. Results of the piping failure probability assessments for NPS 2.



(a) For Temperature at Pipe Weld: 150˚F

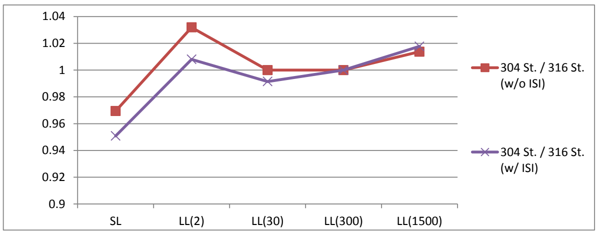


(b) For Temperature at Pipe Weld: 350˚F

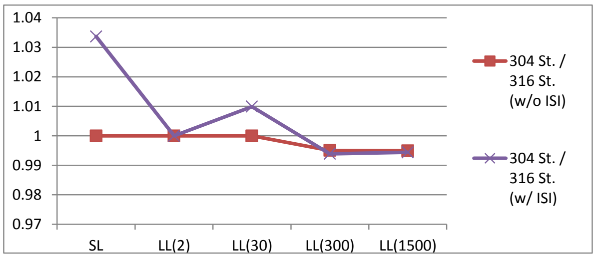


(c) For Temperature at Pipe Weld: 550˚F

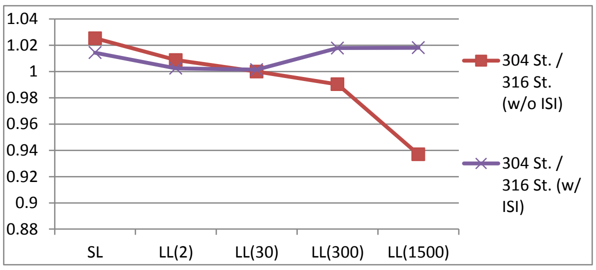
Fig. 3. Results of the piping failure probability assessments for NPS 5.



(a) For Temperature at Pipe Weld: 150˚F



(b) For Temperature at Pipe Weld: 350˚F



(c) For Temperature at Pipe Weld: 550˚F

Fig. 4. Results of the piping failure probability assessments for NPS 16.

disabling leak rate 30 gpm without ISI of 304 St is estimated to be 40% lower than that of 316 St. And the piping failure probabilities with other disabling leak rates regardless ISI are calculated to be similar.

However, for the temperature at pipe weld, 350˚F, the piping failure probability with disabling leak rate 30 gpm without ISI of 304 St is estimated to be 40% higher than that of 316 St. And the piping failure probabilities with other disabling leak rate regardless ISI are calculated to be similar.

For the temperature at pipe weld, 550˚F, the piping failure probabilities with disabling leak rate 30, 300, 1500 gpm with ISI of 304 St are estimated to be 20% higher than that of 316 St. It means that ISI on 304 St of NPS 2 piping with these leak rates has better data in this temperature than ISI on 316 St. And the piping failure probabilities with other disabling leak rates regardless ISI are calculated to be similar.

2.3.2. Results of NPS 5

The results of the piping failure probability assessments for NPS 5 are shown in Fig. 3. For the temperature at pipe weld, 150˚F, the piping failure probabilities with disabling leak rate 300 and 1500 gpm without ISI of 304 St are estimated to be 8% higher than that of 316 St. And the piping failure probabilities with other disabling leak rates regardless ISI are calculated to be similar.

For the temperature at pipe weld, 350˚F, the piping failure probability with small leak with ISI of 304 St is estimated to be 5% higher than that of 316 St. And the piping failure probabilities with disabling leak rates 2 and 30 gpm, regardless ISI are estimated to be 2~3% higher than that of 316 St.

For the temperature at pipe weld, 550˚F, the piping failure probability with disabling leak rate 2 gpm with ISI or without ISI of 304 St is estimated to be 2~3% higher than that of 316 St. And the piping failure probabilities with other disabling leak rate are calculated to be similar.

2.3.3. Results of NPS 16

The results of the piping failure probability assessments for NPS 16 are shown in Fig. 4. For the temperature at pipe weld, 150˚F, the piping failure probability with small leak of 304 St is estimated to be 3~5% lower than that of 316 St. And the piping failure probability with disabling leak rate 2 gpm without ISI is estimated to be 2~3% higher than that of 316 St.

For the temperature at pipe weld, 350˚F, the piping failure probability with small leak with ISI of 304 St is estimated to be 5% higher than that of 316 St. And the piping failure probabilities with disabling leak rate 2 and 30 gpm regardless ISI are estimated to be 2~3% higher than that of 316 St.

For the temperature at pipe weld, 550˚F, the piping failure probability with disabling leak rate 1500 gpm without ISI of 304 St is estimated to be 6% lower than that of 316 St. It means that ISI on 304 St of NPS 16 piping with leak rate 1500 gpm has better data in this temperature than ISI on 316 St. And the piping failure probabilities with other disabling leak rate are calculated to be similar.

3. Conclusions

In developing of a RI-ISI program, there are material differences depending on the nuclear power plants between 304 St and 316 St on segments of the same location. To have a better understanding of effects of the types of piping material, a set of sensitivity assessment using SRRA software is performed. To find the effects of NPS changes, temperature at pipe weld and leak rates, the assessments are performed for NPS: 2, 5, 16; temperature at pipe weld: 150˚F, 350˚F, 550˚F; and leak rate: Small Leak(SL) and Large Leaks(LL: 2, 30, 300, 1500 gpm).

For NPS 2, the piping failure probability for the temperature at pipe weld, 150˚F, with disabling leak rate 30 gpm without ISI of 304 St is estimated to be 40% lower than that of 316 St. However, the piping failure probability for the temperature at pipe weld, 350˚F, with disabling leak rate 30 gpm without ISI of 304 St is estimated to be 40% higher than that of 316 St.

For NPS 5 and NPS 16, the piping failure probability differences between 304 St and 316 St are smaller than the piping failure probability differences between 304 St and 316 St for NPS 2.

From the above results, the piping failure probabilities depend on materials 316 St NPS 2 piping is much better than 304 St NPS 2 piping on medium temperature.

In general, 316 St is better than 304 St in the elevated temperature. However, from the above results, the piping failure probabilities depend on not only material types but also nominal pipe sizes, disabling leak rates and with/without ISI. Most results show that there are no differences between the piping failure probabilities of 304 St and 316 St.

To get more detail understanding of the differences between 304 St and 316 St material types in SRRA software, further sensitivity assessments are thought to be required.

REFERENCES

[1] Westinghouse Electric Company, WCAP-14572, Revision 1-NP-A, "Westinghouse Owners Group Application of Risk-Informed Methods to Piping Inservice Inspection Topical Report," February 1999.

[2] Westinghouse Electric Company, WCAP-14572, Revision 1-NP-A, Supplement 1, "Westinghouse Structural Reliability and Risk Assessment (SRRA) Model for Piping Risk-Informed Inservice Inspection," February 1999.

[3] Westinghouse Electric Company, SAE/RRA-070 (00), Revision 4, "Risk-Informed Inservice Inspection (RI-ISI) Piping Failure Probability Assessment Using Structural Reliability and Risk Assessment (SRRA) Guidance Document," August 2000.