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THE APPLICATIONS OF RISK-INFORMED IN-SERVICE-INSPECTION

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ABSTRACT

The US NRC and nuclear industry encouraged the applications of risk-informed In-Service Inspection（RI-ISI）which can be a alternative program to the ASME Section XI In-service Inspection requirements. The Implementation of RI-ISI can improve the substantial cost as well as does reductions. From the aspect of defense in depth for nuclear safety, the achievements of these procedures can identify the inspection rank to promote the integrity of the current inspection program. Thus, this study utilizes this techniques to implement risk assessment on safety class 1 recirculation piping welds where sensitized to IGSCC of Taibei BWR-6 nuclear power plant. In the evaluation process, WinPraise code is used to calculate the failure probabilities of all welds. The result of risk evaluations can be referred to the further regulatory and plant operation.

Keywords: risk-informed , IGSCC, In-Service Inspection, WinPraise Code

1. INTRODUCTION

The USNRC had developed regulatory guide R.G. 1.174 (R.G. 1.174 1998) and standard review plans Chapter 3 (Standard Review Plans 1998) for risk-informed applications to encourage the implementation of risk-informed regulations(M. A. Caruso, et.al 1999). During the past several years, both USNRC and the nuclear industry have recognized that the risk-informed in-service inspection (RI-ISI) can be used increasingly as a tool in regulatory decision-making(M.E. Mayfield, et.al. 2000). The methodology and procedure for risk-informed in-service inspection proposed by EPRI for BWR (L. A. Shay *et. al.* 2000) and Westinghouse Owners Group for PWR(K. R. Balkey *et. al.* 2000, C. L. Boggess, *et. al.* 2002) have been approved in 1998 and 1999, respectively. The applications of these methodologies have shown substantial cost reductions (60 to 85%) as well as dose reduction (90%) (P. O'Regan 2000).

The implementations of RI-ISI can improve the effectiveness of inspection on the high safety significant components, reduce inspection requirements on piping components, increase the plant availability, enhanced safety measures, and reduce overall operation and maintenance costs. Several plants in USA also implemented RI-ISI incorporated with other augmented inspection programs (e.g. thermal fatigue, IGSCC and erosion-corrosion) (G. Vinod *et. al.* 2003). From the points of the safety concern, the achievements of these procedures can identify the inspection rank to promote the effectiveness of the present inspection program.

The weld cracking due to the intergranular stress corrosion cracking (IGSCC) of the recirculation piping system is still safety issue in the aging/degradation program in Taibei BWR-6(K. Ting 1999, K. Ting and W.W. Chao 2000). The weld overlay according to ASME Code Case N-504 was the primary repairs for the identified flaws in the recirculation piping. The 10-years ISI program including the augmented inspections to the IGSCC-susceptible welds more conservative than the requirements of NUREG-0313 Rev. 2 and GL -88-01 implemented in each outage schedule of Taibei BWR-6. Several investigators have been devoted the RI-ISI procedure to study the inspection program addressing the IGSCC with weld overlay (K. N. Fleming and J. Mitman 2000, M. R. Graybeal 2000, B. Brickstada *et. al.* 2000). They showed that the inspection number can be significantly reduced. Thus, this paper will present the benefit of the implementations of RI-ISI program to welds susceptible to IGSCC based on the process described in Regulatory Guide 1.178 (Regulatory Guide 1.178 1998) and ASME Code Case N-577(ASME 1997). The results of the risk evaluations for the recirculation piping system in Taibei BWR-6 corresponding to the requirements of NUREG-0313 Rev. 2 and current inspection program are compared in this paper.

2. RISK INFORMED PROCEDURES

The risk informed approach is used to establish the inspection program for welds susceptible to IGSCC of the recirculation piping system herein. All failures of the welds would result in the same loss of function defining from the plant PRA. The procedures of RI-ISI are conducted as the following steps.

1. Evaluate consequences of pipe rupture

Consequences of piping failure can be acquired by reviewing the event trees in PRA analysis. When piping failure could result in a plant trip, the plant model is re-evaluated for the associated initiating event with any other impact. The resulting CDF_{IE} value is then be normalized as a conditional core damage probability(*CCDP*), i.e.

$$CCDP = CDF_{IE} / F_{IE} \tag{1}$$

where F_{IE} is frequency of the initiating event.

2. Evaluate failure rate（*FR*）

The failure rate of each weld susceptible to IGSCC of recirculation piping system is expressed in failure probability per year(*FR*). The failure probability(*FP*) is calculated by the software WinPraise (D.O. Harris and D. Dedhia 1998). The parameters considering in WinPraise include pipe sizes, material, sustained stress, water chemistry, operation temperature, residual stress and transient state etc.

$$FR = FP / (inspection \quad period) \tag{2}$$

3. Definition of the risk

In general, the risk associated with the failure at a given location is calculated by multiplying the pipe failure rate by the conditional core damage probability.

$$CDF_i = FR_i \bullet CCDP \tag{3}$$

4. Defining the measurement of the rank of the welds

When the risk associated with each location has been determined, the total risk i.e. total CDF due to IGSCC is the sum of the risk of all the locations. This value can be used to calculate the metrics to rank the welds. The primary metric selected herein is *Risk Reduction Worth* (*RRW*). *RRW* is the ration of total risk to the decrease risk with the individual weld assumed to be perfectly reliable. RRW is defined as:

$$RRW_i = \frac{CDF_{total}}{CDF_i^-} = \frac{CDF_{total}}{CDF_{total} - CDF_i} \tag{4}$$

The welds are ranked by their risk values. Per NUMARC 93-01 (NUMARC 1996), all welds of RRW>1.005 are considered as High Safety Significant.

3. RESULTS AND DISCUSSION

This paper studies the risk evaluation of recirculation piping system of BWR-6 including two loops A and B as shown in Figure 1. Each loop includes suction, discharge, ring header and 5 risers. There are 57 and 59 welds corresponding Loop A and Loop B, respectively. All the welds in the recirculation line are shown in Table 1. The materials of piping were 304 stainless steel. The standard weld overlay designs were used to repair the IGSCC welds. The stress results of each weld used in the WinPraise software are based on the stress analysis of 20 years operation. This paper discusses the risk rank of the in-service inspection program about the recirculation piping welds in the next 20-years operation.

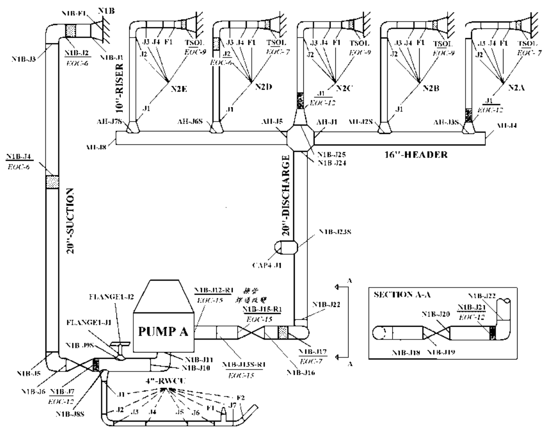

Figure 1(a) Loop A of the recirculation piping system

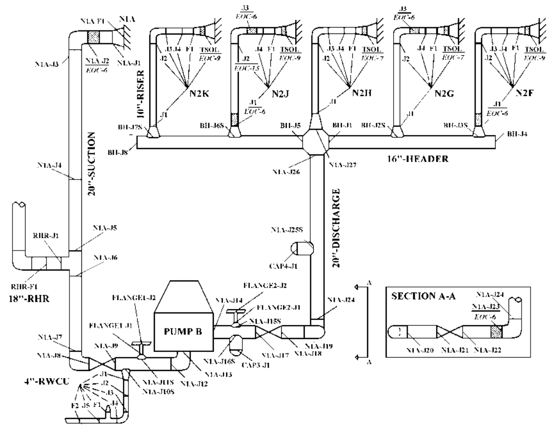

Figure 1(b) Loop B of the recirculation piping system

The large, medium and small LOCAs in the recirculation piping are considered as the initiating events due to the weld susceptible IGSCC. The results of the core damage frequency (CDF_{IE}) and frequency for each LOCA can obtain from the PRA results (J.C. Yao, 1998) as shown in Table 2. The conditional core damage probability *CCDP* for large, medium and small LOCA by Eq.(1) is also listed in Table 2. The medium LOCA may cause core damage higher than large LOCA and small LOCA, the medium LOCA is selected for the initial events for the risk analysis in this paper. For the large and small LOCA initiating events, low pressure flooding or high pressure spraying emergency system can be used as the make up system. The inventory leakage for medium LOCA is between the large and small range, the high pressure or low pressure system supplying inventory cannot be used directly. Corrective judgments and activities to maintain the inventory supplying system for the suitable pressure and flow rate make the emergency procedures complicated. Thus, the risk evaluation focus on the medium LOCA is more conservative and reasonable.

Table 1 Welds in the recirculation piping system

Loop	Segments	Description	Weld numbers	Weld Identifications
A	RR-001	19” suction piping from reactor to recirculation pump A	10	N1B-F1,N1B-J1,N1B-J2,N1B-J3,N1B-J4,N1B-J5, N1B-J6,N1B-J7,N1B-J10,N1B-J11
	RR-002	20” discharging piping from recirculation pump A to ring header	11	N1B-J12,N1B-J15,N1B-J16, N1B-J17, N1B-J18, N1B-J19,N1B-J20,N1B-J21, N1B-J22, N1B-J24, N1B-J25
	RR-003	16” piping of ring header of loop A	6	AH-J1,AH-J2S,AH-J3S,AH-J5,AH-J6S, AH-J7S
	RR-004	10” riser from ring header to reactor nozzle F	6	N2A-J1,N2A-J2,N2A-J3,N2A-J4,N2A-F1,N2A-F2
	RR-005	10” riser from ring header to reactor nozzle G	6	N2B-J1,N2B-J2,N2B-J3,N2B-J4,N2B-F1, N2B-F2
	RR-006	10” riser from ring header to reactor nozzle H	6	N2C-J1,N2C-J2,N2C-J3,N2C-J4,N2C-F1, N2C-F2
	RR-007	10” riser from ring header to reactor nozzle J	6	N2D-J1,N2D-J2,N2D-J3,N2D-J4,N2D-F1,N2D-F2
	RR-008	10” riser from ring header to reactor nozzle K	6	N2E-J1,N2E-J2,N2E-J3,N2E-J4,N2E-F1, N2E-F2
B	RR-009	19” suction piping from reactor to recirculation pump B	12	N1A-F1,N1A-J1,N1A-J2,N1A-J3,N1A-J4,N1A-J5 N1A-J6,N1A-J7,N1A-J8,N1A-J9,N1A-J12,N1A-J13
	RR-010	20” discharging piping from recirculation pump B to ring header	11	N1A-J14,N1A-J17,N1A-J18,N1A-J19,N1A-J20,N1A-J21 N1A-J22,N1A-J23,N1A-J24,N1A-J26,N1A-J27
	RR-011	16” piping of ring header of loop B	6	BH-J1,BH-J2S,BH-J3S,BH-J5,BH-J6S,BH-J7S
	RR-012	10” riser from ring header to reactor nozzle A	6	N2F-J1,N2F-J2,N2F-J3,N2F-J4,N2F-F1, N2F-F2
	RR-013	10” riser from ring header to reactor nozzle B	6	N2G-J1,N2G-J2,N2G-J3,N2G-J4,N2G-F1,N2G-F2
	RR-014	10” riser from ring header to reactor nozzle C	6	N2H-J1,N2H-J2,N2H-J3,N2H-J4,N2H-F1,N2H-F2
	RR-015	10” riser from ring header to reactor nozzle D	6	N2J-J1,N2J-J2,N2J-J3,N2J-J4,N2J-F1,N2J-F2
	RR-016	10” riser from ring header to reactor nozzle E	6	N2K-J1,N2K-J2,N2K-J3,N2K-J4,N2K-F1,N2K-F2

Table 2 CCDP values of three cases of LOCA events

CDF_{IE}/F_{IE} (Large Break)	CDF_{IE}/F_{IE} (Medium Break)	CDF_{IE}/F_{IE} (Small Break)	$CCDP$ (Large Break)	$CCDP$ (Medium Break)	$CCDP$ (Small Break)
$1.7\times10^{-9}/1.0\times10^{-4}$	$1.1\times10^{-6}/3.0\times10^{-4}$	$3.2\times10^{-8}/3.0\times10^{-3}$	1.7×10^{-5}	3.67×10^{-3}	1.07×10^{-5}

Table 3 lists high safety significant welds with RRW>1.005 for the medium LOCA. The ranks of the welds are also shown in sequences. The percents of the accumulated contributions of CDF_i for the implementations of RI-ISI of each weld are also shown in Table 3. There are 17 welds to be identified as the high safety significant components whose core damage frequency on the medium break has devoted to 93.55% contributions. The augment inspections corresponding to these 17 welds can reduce the risk under 6.45% due to the medium break. Table 3 also shows the values of CDF_i corresponding to the inspection programs based on NUREG-0313 Rev. 2 (NUREG 1988) and current Taibei licensee inspection program. The current Taibei inspection program was conserved more than the requirements of NUREG-0313 Rev. 2 and GL 88-01.

Table 3 High safety significant welds for the medium LOCA

Weld ID.	Weld Category	CDF_i	Accumulated contributions of CDF_i%	*RRW*	CDF_i (inspection program based on NUREG-0313)	CDF_i (current inspection program)
N2H-J4	B	1.32E-04	27.97%	1.388	1.32E-04	8.17E-05
N2J-J4	B	1.13E-04	51.84%	1.314	1.13E-04	6.05E-05
N2G-J4	B	6.03E-05	64.56%	1.146	6.03E-05	2.71E-05
N2H-F2	D	3.39E-05	71.73%	1.077	1.52E-05	7.10E-06
N2J-F2	D	2.17E-05	76.31%	1.048	9.59E-06	9.59E-06
N2H-J2	E	1.88E-05	80.29%	1.041	8.57E-06	7.10E-06
N2D-J4	B	9.88E-06	82.37%	1.021	9.88E-06	4.35E-06
N2J-J2	A	9.45E-06	84.37%	1.020	9.45E-06	7.78E-06
N2G-F2	D	8.11E-06	86.08%	1.017	3.44E-06	3.44E-06
BH-J6S	A	6.62E-06	87.48%	1.014	6.62E-06	5.81E-06
N2A-J4	B	6.30E-06	88.81%	1.013	6.30E-06	2.75E-06
N2K-J4	B	4.67E-06	89.79%	1.010	4.67E-06	2.01E-06
N1A-J27	B	4.53E-06	90.75%	1.010	4.53E-06	2.76E-06
BH-J2S	A	4.01E-06	91.60%	1.009	4.01E-06	3.54E-06
N2G-J2	A	3.32E-06	92.30%	1.007	3.32E-06	2.75E-06
N2F-J4	B	3.21E-06	92.98%	1.007	3.21E-06	1.37E-06
AH-J3S	A	2.69E-06	93.55%	1.006	2.69E-06	2.46E-06

Table 4 shows the reduced effectiveness of the implementation of ISI inspection program considering of requirements of NUREG-0313 and Taiwan's inspection program for the high safety significant welds.If the inspections of the susceptible IGSCC welds are concentrated on the high significant welds in the next 20 years, the total numbers of inspected welds are 89 and 35 based on the current Taibei inspection program and the requirements of NUREG-0313, respectively. The percentage of risk reduction is 47.62% and 10.32% based on the current Taibei inspection program and the requirements, respectively. The inspections based on current Taibei inspection program are 142% higher than the case of NUREG-0313, the risk reduction can reach 36.81%. Obviously, the current inspection program might be too conservative. Therefore, the inspection program can be focused on high safety significant instead of entirely welds in order to save the inspection resources and maintain plant's defense in depth as well.

Table 4 The effectiveness of the high safety significant welds during the 20-year period

Weld Category	Number of Welds	Inspection number based on NUREG-0313	Inspection number based on Taibei inspection program
A	5	3	10
B	8	8	48
D	3	18	18
E	1	6	13
Total	17	35	89
Accumulated contributions of CDF_i		3.973E-04	2.320E-04
The risk reduction		10.32%	47.62%

Table 5 shows the contributions of CDF_i for 16 segments in RI-ISI program. From the result of table 5, 10 segments include high safety significant welds and the highest safety significant welds distribute to 3 segments that are Riser N2B of Loop B, Riser N2C of Loop B and Riser N2D of Loop B. The average contribution of CDF_i for each weld of these three segments is higher than other segments from 2.60% and 6.62%. Therefore, it should be considered as the critical locations for the improved inspection program.

Table 6 lists the contribution of CDF_i for each werd category and average contribution of each weld in accordance with weld category. The average contribution of each weld of category E is lower than the other categories. In this category E, there are 10 low safety significant welds have conducted standard weld overlays during the past outages. Thus, the implementations of weld overlay have the positive effective for high safety significant piping system.

Table 5 Percentage of high safety significant welds corresponding to each segment

Segment	Numbers of Welds contribute to high safety significant	Numbers of Welds	*Total* CDF_i	*Contributions of* CDF_i	Average Contribution of each weld
Suction region of loop A	0	10	1.43E-07	0.03%	0.00%
Discharge region of loop A	0	11	5.73E-08	0.01%	0.00%
Ring header of loop A	1	6	4.41E-06	0.93%	0.16%
Riser N2F of loop A	1	6	9.14E-06	1.93%	0.32%
Riser N2G of loop A	0	6	3.09E-06	0.65%	0.11%
Riser N2H of loop A	0	6	2.43E-06	0.51%	0.09%
Riser N2J of loop A	1	6	1.07E-05	2.26%	0.38%
Riser N2K of loop A	0	6	3.15E-07	0.07%	0.01%
Suction region of loop B	0	12	1.72E-07	0.04%	0.00%
Discharge region of loop B	1	11	4.64E-06	0.98%	0.09%
Ring header of loop B	2	6	1.58E-05	3.34%	0.56%
Riser N2A of loop B	1	6	5.33E-06	1.13%	0.19%
Riser N2B of loop B	3	6	7.38E-05	15.59%	2.60%
Riser N2C of loop B	3	6	1.88E-04	39.71%	6.62%
Riser N2D of loop B	3	6	1.48E-04	31.23%	5.20%
Riser N2E of loop B	1	6	7.56E-06	1.60%	0.27%
Total	17	116	4.74E-04	100.00%	

Table 6 The contributions of CDF_i *to each weld category*

Weld category	Numbers of welds for high safety significant	Numbers of Welds	*Total* CDF_i	*Contribution of* CDF_i	Average contribution of each weld
A	5	37	3.35E-05	7.08%	0.19%
B	8	52	3.47E-04	73.29%	1.41%
D	3	12	6.48E-05	13.68%	1.14%
E	1	15	2.82E-05	5.95%	0.40%
Total	17	116	4.74E-04	100.00%	

4. CONCLUSION

This study presents risk informed technique on the recirculation piping system susceptible to IGSCC. WinPraise software package simulates and calculates the failure probability for each weld. Using risk informed assessments, the risk of each weld can be quantified and ranked. The results of the risk evaluation can be referenced to the regulation for the improved inspection program in the near future.

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