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Integrated Guidelines for Management of Alloy 600 Locations

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1. Introduction

It is well known that alloy 600 material is susceptible to primary water stress corrosion cracking(PWSCC) in pressurized water reactor environment. The locations experiencing PWSCC include steam generator tubes, pressurizer instrumental nozzles, control rod driving mechanism(CRDM) penetration nozzles, reactor outlet nozzles, and bottom mounted instrumental(BMI) nozzles.

In order to ensure the safety of nuclear power plants(NPPs), the needs for careful management of alloy 600 location have been arising. Korea Hydro & Nuclear Power Co.(KHNP) has developed integrated guidelines for management of alloy 600 locations and the guidelines are under review by the regulator. The guidelines consist of alloy 600 location database, inspection program, maintenance/preventive maintenance method, and finally water chemistry management for PWSCC mitigation. In this paper, the detailed contents are presented.

2. Alloy 600 Location Database

Main alloy 600 locations can be classified into five major groups: reactor upper head penetration nozzles, reactor lower head instrumental penetration nozzles, dissimilar metal butt weld nozzles, pressurizer heater sleeves, and finally, small diameter penetration nozzles. The configuration of alloy 600 locations in a plant can be different from other NPPs according to design model or construction period. KHNP has constructed database for alloy 600 locations for fourteen units. The excel program based database includes information on materials, design and manufacturing history as well as drawings for each location.

3. Inspection Program

The in-service inspection program for detecting PWSCC uses ultrasonic technique(UT) and bare metal visual(BMV) inspection as main inspection methods for detecting cracks or leakage of boric acids. As auxiliary methods, eddy current technique and penetrant technique can be employed to detect micro-scale cracks or confirm whether the cracks open to surface or not. In this chapter, detailed information on each non-destructive evaluation(NDE) technique is presented and appropriate inspection techniques are provided for five major alloy 600 location groups. It also handles inspection qualification, procedure, and database management as well as performance demonstration of ultrasonic test for reactor upper head penetration nozzles, and dissimilar metal butt welds. Furthermore, maintenance criteria including crack acceptance criteria and crack growth evaluation are presented for reactor upper head penetration nozzles and dissimilar metal butt welds in addition to the information on inspection scope and interval for each location group given in Table I.

Table I: Inspection methods and intervals for each location

Location	Method	Inspection Interval			
Reactor upper head penetration nozzles (CC N729-1)	BMV	1 outage			3 outages (5 years)
		7 units			Others
	UT	1 O/H	2 O/H	8 yrs	10 yrs
		6 units	1 unit	6 units	Others
Reactor lower head penetration nozzles (CC N722-1)	BMV	2 outages			
		14 units			
Butt welds (CC N770-1)	BMV	1 O/H		10 yrs	
		Pressurizer, hot leg		Cold leg	
	UT	2 O/H		5 yrs	2 period (<7 yrs)
		pressurizer		Hot leg	Cold leg
Pressurizer heater sleeve (CC N722-1)	BMV	1 O/H		Not applied	
		6 units		8 units	
Instrumental and small diameter nozzle (CC N722-1)	BMV	Pressurizer	Hot leg	Cold leg	Not applied
		1 O/H	1 O/H	10 yrs	
		6 units			8 units

4. Maintenance/Preventive Maintenance Method

While maintenance is defined as activities to restore the intended safety function and performance of structures, systems and components when their designed function and performance become low, preventive maintenance indicates pre-emptive repair or replacement of the components susceptible to PWSCC as well as mitigation maintenance of crack initiation and growth. These guidelines suggest eight maintenance/preventive maintenance methods that can be applied to alloy 600 locations: four methods are for penetration nozzles and the others are for butt welds.

4.1 Maintenance Methods for Penetration Nozzles

Seal weld repair(SWR) method can be applied to reactor upper head penetration nozzles. One of the features of this method is to perform weld overlay on the cracking location with PWSCC resistance weld metal without the removal of pre-existing flaws in the nozzles or welds. The topical report on this method has been approved by United States Nuclear Regulatory Commission (USNRC).

Mid wall weld repair(MWR) method had been employed in J-groove welds such as reactor upper head CRDM penetration nozzles, and pressurizer heater sleeve when flaws were detected. In this method, the nozzle having flaws is cut at the center of head wall to remove some portion of the nozzle first and then, welding of the remained portion of nozzle to head wall at the inner diameter side for constructing new pressure boundary is carried out.

Half nozzle repair(HNR) method can be also applied to J-groove welds such as reactor upper head CRDM penetration nozzles, pressurizer heater sleeve, and instrumental penetration nozzles. Similarly to MNR, some portion of the nozzle is removed to construct new pressure boundary. But it needs pad welding on the outer surface of the head to install new PWSCC resistant nozzle and hence, it can be used to repair small diameter nozzles.

Mechanical nozzle seal assembly(MNSA) has been developed for the instrumental nozzles smaller than two inches that are installed in pressurizers, steam generators, and hot/cold leg pipes. MNSA makes sealing on the interface between instrumental nozzles and pressurizers or reactor coolant system pipes by compressing Grafoil seal.

4.2 Maintenance Methods for Butt Welds

Weld overlay is a kind of preventive maintenance method that can be applied to PWSCC susceptible butt welds. It prevents PWSCC from growing by performing weld overlay with PWSCC resistant weld material on the outer surface of alloy 82/182 butt welds. When the thickness of weld overlay is more than one third of the pipe thickness to secure structural integrity with weld overlay thickness itself, we call it full structural weld overlay(FSWOL). In optimized weld overlay(OWOL), the thickness of weld overlay is rather thinner. But it was confirmed that only one or two weld layers can reduce residual stress enough not to initiate PWSCC.

Weld inlay or weld onlay is one of maintenance method for retarding PWSCC initiation and growth by isolating alloy 600 weld material from reactor coolant environment.

Mechanical stress improvement process(MSIP) has been developed to convert the residual tensile stress to compressive stress up to the 50% of pipe wall thickness by causing the minimum permanent mechanical deformation on the outer surface of pipes or nozzles near the welds. It is worthwhile to note that it can also applied to the weld with surface flaws as a repair method when the crack depth is less than 30% of pipe wall thickness.

5. Water Chemistry Management for PWSCC Mitigation

Zinc injection and increase of dissolved oxygen are water management method for reducing PWSCC. Injected zinc substitutes nickel or cobalt in the inner oxide layer and retards corrosion by making the oxide layer the most stable compound, resulting in the decrease of PWSCC and radiation.

It is known that the growth rate of PWSCC is the maximum when the concentration of dissolved oxygen corresponds to Ni/NiO equilibrium. From several experimental results, it was confirmed that PWSCC growth rate can be controlled by the concentration of dissolved oxygen. In this regard, KHNP is now considering operation in higher dissolved oxygen concentration to reduce PWSCC growth rate.

3. Conclusions

The integrated guidelines collected all relevant information on the management of alloy 600 locations. This information may be useful for establishing the most effective preventive maintenance strategies by prioritization in addition to maintenance strategies. Table II summarize maintenance strategies for alloy 600 locations.

Table II: Maintenance strategies for alloy 600 locations.

Location		Preventive maintenance /mitigation	Maintenance
Reactor upper head penetrations	Hot head(alloy 600 welds/alloy 690 base metal)	WOL	SWR
	Cold head	Peening	SWR
Reactor lower head penetrations		Peening	HNR MNSA-2
Dissimilar metal butt welds		MSIP	WOL Weld Inlay(RV only) MSIP
Pressurizer heater sleeve/ small diameter penetrations		-	HNR