Application Research of Decontamination Process of Primary Coolant Pump in Nuclear Power Plant

Qiang WU, DongBiao FU, XingYu GAO, Jing ZHANG, JianBo ZHANG
China Institute for Radiation Protection, P.O. Box 030006
XueFu street 102#, TaiYuan, ShanXi ,China, wuqiang1211@yahoo.com.cn

Abstract：In decontamination process of primary coolant pump in nuclear power plant, three kinds of nuclear decontamination methods were applied and compared. Dose rate reduction factor (DRRF) range of ultrasonic decontamination process, chemical decontamination process and ultrasound - chemical united decontamination process are 1.49--6.38, 10.22--176 and 7.39--56.31 separately, and decontamination factor (DF) range are 1.65 -->1980, 1.9-->421.9 and 145-->37033 separately. The corrosion depth of two kinds of stainless steel samples which were treated by ultrasound - chemical united decontamination process are less than 100nm. So ultrasound - chemical united decontamination process can be used as an optimized decontamination process for primary coolant pump.

Keyword：Decontamination process；Primary coolant pump；Nuclear power plant

1. Introduction

In nuclear power plant (NPP), decontamination is an important work through which radioactive-bearing deposits are removed from the interior surface of piping and components. Decontamination technology is routinely performed in nuclear power plant and is an effective way for dealing with high shutdown radiation fields(Smee，1999). With the development of decontamination technology, radioactive decontamination method becomes a multi-disciplinary, multi-category, cross-cutting systems technology. In general, there are four kinds of decontamination methods: Chemical, physical, phys-chemical, and biological method(Qiang, 1999). In specific applications, these methods can be applied alone or unitedly. In engineering application, physical decontamination methods comprise ultrasonic (Qiang, 2007), high pressure water jet(Chengliang, 1998), and stripping wipe. Chemical decontamination includes oxidation, reduction, oxidation-- reduction complex methods (Ruitang, 1998). In practical application, efficient decontamination requires both cost effective and high decontamination quality under safe conditions. Based on this rule, three kinds of decontamination of primary coolant pump hydraulic assembly were performed in NPP, and the comparison results were presented here in this paper. By comparing the decontamination effect of three kinds of methods, the ultrasonic-chemical united decontamination is recommended as the optimal method.

2. Equipment, reagent and measured method

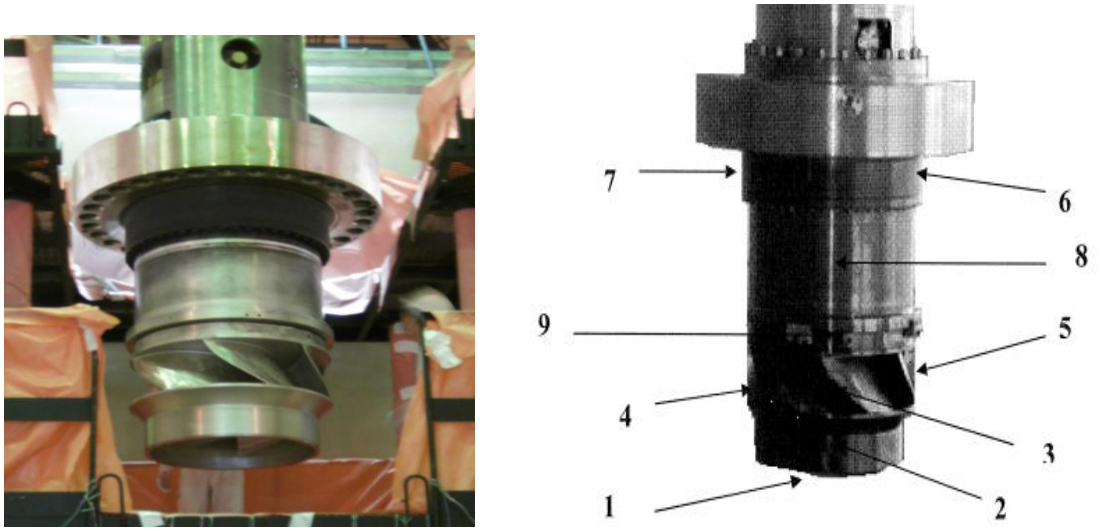
2.1 Equipment

2.1.1 Primary pump hydraulic assembly

In this experiment, the decontamination object is primary coolant pump hydraulic assembly (PPHA). It includes: pump shaft, impeller, steering wheels and other components. These components are welded together by austenitic stainless steel castings. Single-stage impeller is spiral leaves, and steering wheel is installed in the bottom flange of the diffuser. Shape structure is shown in Fig.1a.

2.1.2 Ultrasonic decontamination mobile device

It comprises a decontamination tank, a heating tank, rinse cycle parts, ultrasonic generator and control part as shown in Fig.2a. A hanging basket can be installed in ultrasonic decontamination tank to treat small polluted equipments and parts. The volume is about 2 cubic meters. The parameters of decontamination equipment are shown in Tab.1.



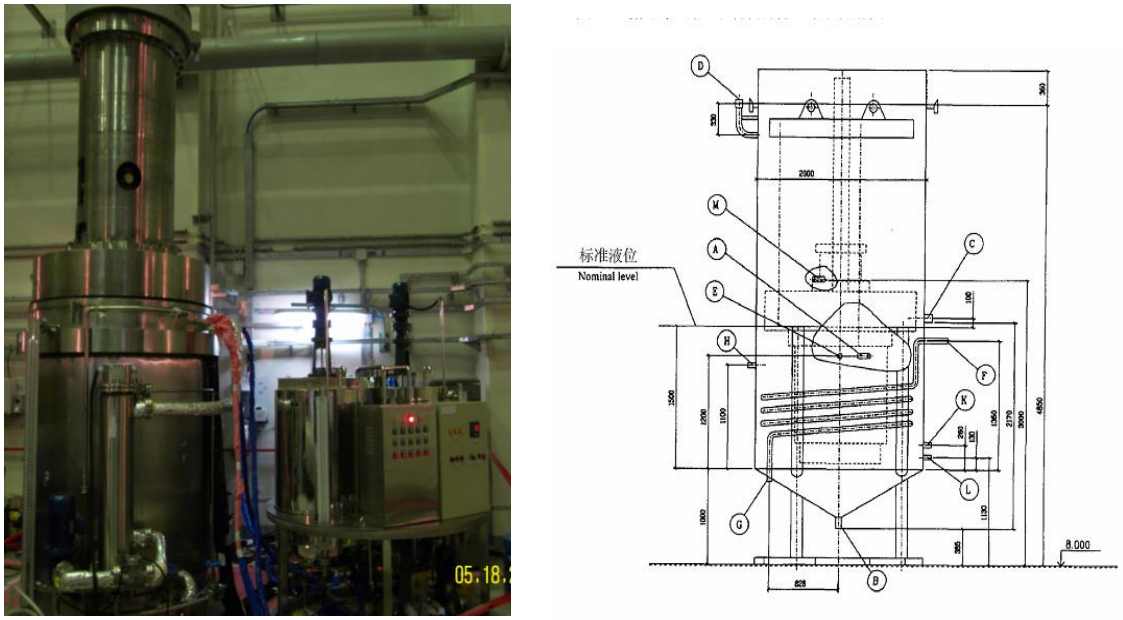
a b

Fig. 1 Picture of primary pump hydraulic assembly

(a: Photograph of primary pump hydraulic assembly , b: Distribution of sampling sits in primary pump hydraulic assembly)

2.1.3 Chemical decontamination system (type FKK40)

FKK40 is a decontamination systems matched with Soviet-made VVER-type pressurized water reactors. It includes the decontamination tank, circulating pump, steam heating pipes, and electrical parts as shown in Fig.2b. The volume is about 5 cubic meters. Parameter of decontamination equipment is shown in Tab.1.



a b

Fig. 2 Picture decontamination equipments

(a: Photograph of mobile ultrasonic decontamination equipment , b: Structure of FKK40 chemical decontamination system)

2.2 Measure instrument

Radiation measure instrument (RMI) type: MIP10+SBM-2D, 6150 AD5/H; scanning electron microscopy (SEM) type: LEO 438VP.

2.3 Reagent

Analytic level reagent: $KMnO_4$, NaOH, $H_2C_2O_4$, $H_8C_6O_7$.

2.4 Corrosion depth test method

Corrosion depth test is according to steel specimen weight-loss method.

3. Decontamination methods

There are 8 sets of PPHA need to decontaminate, 6 sets were decontaminated by ultrasonic decontamination method, 1 set by chemical decontamination method, and 1 set by ultrasonic-chemical united decontamination method.

3.1 Ultrasonic decontamination method

Contaminated PPHA were put in preheated 60 centigrade desalted water in ultrasonic tank (Fig.2 a), then ultrasonic washing was begun for 30mins. After waste discharge, PPHA was rinsed for 5mins. This ultrasonic washing and rinse cycle was performed 2 times.

3.2 Chemical decontamination method

There are two steps in this method. First step is oxide stage. Polluted PPHA was put in solution composed of 0.5g /L Potassium permanganate and 2g/L nitric acid solution at 80 centigrade in tank of FKK40 (Fig.2 b), then washing cycle was performed for 2 hours. After waste discharge, PPHA was rinsed for 5mins. The second step is reduction stage. PPHA was put in 10g/L oxalic acid solution at 80 centigrade in tank, then washing cycle was performed for 2 hours. After waste discharge, then PPHA was rinsed for 5mins.

3.3 The ultrasonic-chemical united decontamination method

This method is ultrasonic and chemical united methods. First step is ultrasound oxide stage. Polluted PPHA was put in solution composed of 0.5g/L Potassium permanganate and 2g/L nitric acid solution at 60 centigrade ultrasonic tank (Fig2a), ultrasound washing was performed for 30mins. After waste discharge, PPHA was rinsed for 5mins. The second step is ultrasound reduction stage. PPHA oxide treated was put in 10g/L oxalic acid solution at 60 centigrade in tank, ultrasound cycle was performed for 30mins. After waste discharge, rinse was performed for 5mins.

4. Result and discussion

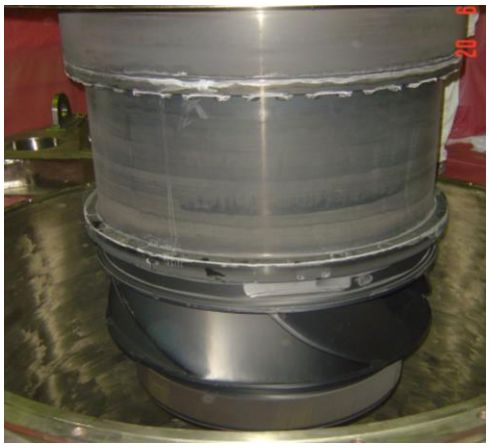
4.1 Decontamination result comparison

We compared the results of three kinds of PPHA decontamination methods. Sampling sites are shown in Fig.1 b. Tab. 2 shows the compared results. The contact dose rate and surface contamination of ultrasonic decontamination method decreased to some extent. The contact dose rate is less than 2.3mSv/h, the surface contamination is less than 2770 Bq/cm^2, and these results meet the requirements of NPP maintenance. Ultrasonic decontamination method can remove loose pollutant in surface of primary pump, but can not remove the black oxide product films completely developed in normal running. Fig.3 a-b show the comparison of before and after ultrasonic decontamination, and the difference are not obvious. The effect of the chemical decontamination method is better than ultrasound decontamination, the contact dose rate and surface contamination was significantly reduced, contact dose rate of 0.178 mSv/h, surface contamination down to 1100 Bq/cm^2. Fig.3 c-d show the comparison of before and after chemical decontamination. Chemical decontamination uses chemical solvents to loosen and remove the corrosion product films, and the surface of PPHA is clean and smooth.

Ultrasound - chemical united decontamination has best decontamination quality among three methods, contact dose rate is less than 0.089mSv/h, surface contamination is less than $40Bq/cm^2$ (DRRF 10--172, DF 2--320). Fig.3 e-f show the effect of ultrasound--chemical united method, we can see PPHA becomes bright and shiny after decontamination.

a

b



c

d

e

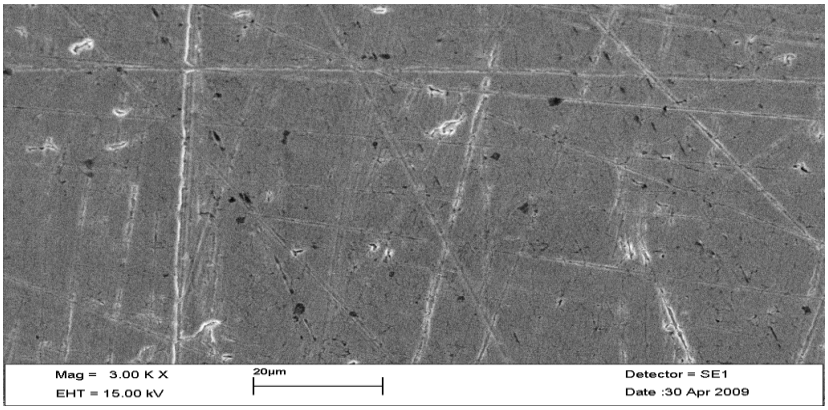
f

Fig. 3 Pictures comparison of primary pump hydraulic assembly before and after decontamination (a: Before ultrasonic decontamination , b: After ultrasonic decontamination, c: Before chemical decontamination, d: After chemical decontamination, e: Before ultrasonic-chemical united decontamination, f : After ultrasonic- chemical united decontamination)

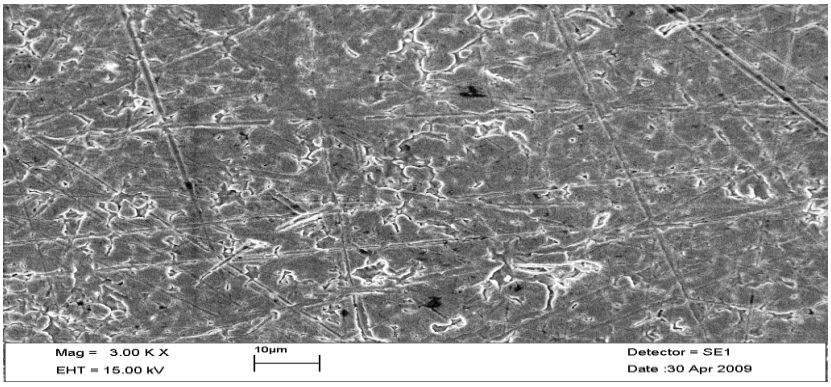
4.2 Substrate corrosion test

We tested the corrosion level of ultrasound - chemical united decontamination method. The experiments were performed on stainless steel specimens(type: 0Cr18Ni9Ti ,1Cr18Ni9Ti) which corresponds to material of PPHA. The total 20 samples were put in cycle tank and were cleaned by ultrasound - chemical decontamination method. After ultrasound - chemical united decontamination operation, corrosion depth of tow kinds of steel sample are 10-37nm and 40-91nm respectively. The results show the corrosion level of ultrasound - chemical united

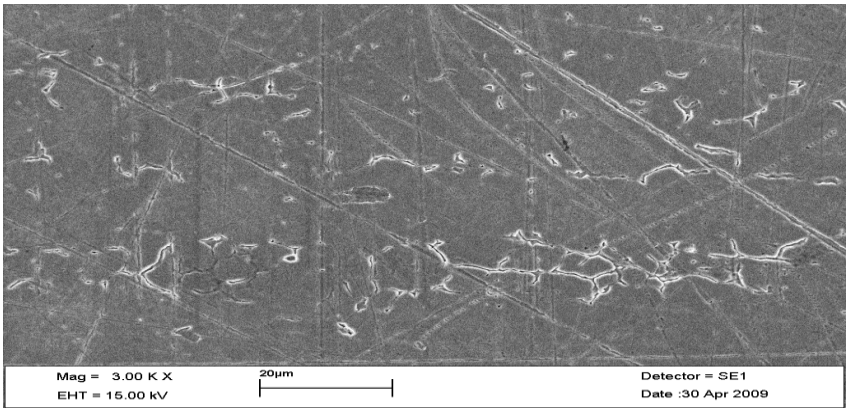
decontamination method of 1Cr18Ni9Ti steel specimen is slightly higher than 0Cr18Ni9Ti , and both of them are far less than 1 μm(decontamination process corrosion limits of NPP). To invest corrosion level, steel specimen was enlarged 3000 times by scanning electron microscopy (SEM). Fig.4 a-d show the comparison results of SEM, and we can see ultrasound--chemical united decontamination process has only minor corrosion on the two kinds of stainless steel sample, and corrosion level of 1Cr18Ni9Ti steel is slightly sever than 0Cr18Ni9Ti. This indicates that the low-carbon stainless steel is more corrosion resistance.



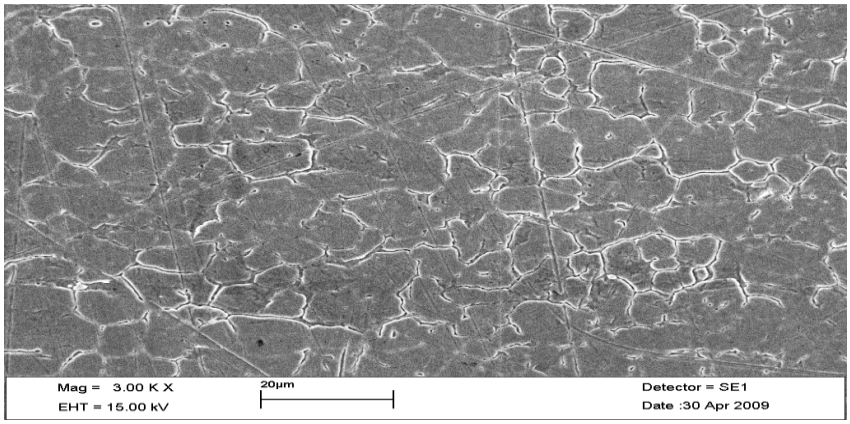
a



b



c



d

Fig. 4 SEM pictures comparison of steel sample (a: sample (1Cr18Ni9Ti) before ultrasonic-chemical united decontamination, b: sample (1Cr18Ni9Ti) after ultrasonic-chemical united decontamination, c: sample(0Cr18Ni9Ti) before U-C united decontamination , d: sample(0Cr18Ni9Ti) after U-C united decontamination

5. Conclusion

Decontamination results of PPHA show that ultrasound-chemical united decontamination method has best decontamination effect in three decontamination methods. In general, decontamination of low-polluted level components is relatively difficult, and decontamination coefficient is low (Jiaheng, 2007). This work shows ultrasound-chemical united decontamination technology has good effects to low level polluted components, and DRRF and DF are significantly higher than other two kinds of methods, and the level of radioactive contamination is less than national standard of 40Bq/cm^2 (CS, 2002). The corrosion depth of ultrasound-chemical united decontamination process is 10-91nm, and this indicates this method has slight damage to the stainless steel substrate and is a safe decontamination method. So that ultrasound--chemical united decontamination process can be used as an optimum PPHA decontamination process in NPP.

6. Acknowledgments

This work was supported by the project team of waste management of NPP (China) and the analysis and testing center of TaiYuan steel factory (China).

7. Reference

Smee J. (1999) Decontamination Handbook. Electric Power Research Institute Report EPRITR-112352.

Qiang Wu (1999) Application of Mechanical Decontamination Technology in nuclear facilities. Radiation Protection Bulletin, 19, 5, 30-34.

Qiang Wu, Chuan Wang (2007) Study on Application of Joint Ultrasound - Chemical Decontamination Technology in Nuclear Power Plants. Applied Chemical Industry, 36, 1, 90-95.

Chengliang Xin, Qizhuang Zhang (1998) Applied summarization of high pressure water jet technology for cleaning line. Chemical Cleaning, 14, 2, 21-24.

Ruitang Zheng, Sikun Xu, Chengze Yu, Yingjie Zheng (1998) Chemical Decontamination in Nuclear Facilities. Chemical Cleaning, 14, 3, 20-25.

Jiaheng He, Wenbing Zhong, Shunzhong Luo (2007) Nuclear Facilities Decontamination Techniques . Radiation Protection Bulletin, 27, 5, 24-27.

China Standard (2003) Basic standards for protection against ionizing radiation and for the safety of radiation sources. Beijing: China Standard Press, 37.

Number	Item	Parameter	
		Mobile ultrasonic decontamination equipment	Chemical decontamination system (FKK40)
1	Main manufacture material	0Cr18Ni9	0Cr18Ni9
2	Working pressure	atmospheric pressure	atmospheric pressure
3	Design temperature	≤ 90 degrees Celsius	≤ 90 degrees Celsius
4	Liquid volume	$2m^3$	$5m^3$
5	Circulation flow rate	$5m^3/h$	$15m^3/h$
6	Ultrasonic Power	≤ 30 kW	
7	Electric heater power	25 kW	
8	Steam heating temperature		180 degrees Celsius

Tab.1 Parameter of decontamination equipment

Number of sample	Dose rate									Surface contamination								
	Before decontamination (mSv/h)			After decontamination (mSv/h)			DRRF			Before decontamination (Bq/cm^2)			After decontamination (Bq/cm^2)			DF		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
1	2.42	1.82	2.7	1.4	0.178	0.084	1.73	10.22	32.1	482	>9999*	545.6	142	200	2.58	3.39	>50	212
2	5.74	7.74	3.3	0.9	0.045	0.059	6.38	172	56.31	>9999*	>9999*	659	5.05	23.7	1.2	>1980	>421.9	514.2
3	6.21	6.01	3	1.09	0.041	0.093	5.7	146.6	32.33	543	>9999*	451	82.6	650	0.89	6.57	>15.38	506.7
4	3.11	2.64	2.9	1.2	0.015	0.072	2.59	176	40.11	1120	2100	>9999*	6.9	1100	0.27	162.3	1.9	>37033
5	2.33	1.31	3.3	1.56	0.085	0.089	1.49	15.4	37.12	379	8791	106	229	528	0.73	1.65	16.65	145
6	2.2	1.34	0.69	0.78	0.032	0.039	2.82	41.88	17.74	>9999*	>9999*	>9999*	101	31	39.8	>99	>322.55	>201
7	3.17	2.07	0.58	0.56	0.016	0.065	5.66	129.4	8.91	>9999*	>9999*	>9999*	2770	51	0.46	>3.61	>196.06	>21737
8	3.58	1.98	1.02	2.3	0.072	0.014	1.56	27.5	7.39	>9999*	482	>9999*	308	17.5	0.46	>32.46	27.54	>21737
9	1.42	1.26	1.03	0.45	0.053	0.058	3.16	23.77	17.64	930	>9999*	>9999*	46.7	46.5	0.35	19.9	>215	>28569

Ⅰ: ultrasonic technology, Ⅱ: chemical technology, Ⅲ: ultrasonic-chemical united technology,

*: full scale

Tab.2. Decontamination results of primary pump hydraulic assembly