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FULL SYSTEM DECONTAMINATION WITH HP/CORD® UV FOR DECOMMISSIONING OF THE GERMAN PWR STADE

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Abstract

Minimization of personnel dose rates and generation of material for free release is a must and requires Full System Decontamination (FSD) as a first measure when decommissioning Nuclear Power Plants.

Framatome ANP received the contract for FSD at the German Pressurized Water Reactor (PWR) Stade (680 MWe). The plant was shut down in November 2003 after 31 years of operation. Decontamination was performed of the complete primary circuit and of the main auxiliary systems i.e. Residual Heat Removal System (RHR), Reactor Water Clean-up System (RWCU), Volume Control System (VCS). The applied decontamination process HP/CORD® UV (patented decontamination process of Framatome ANP) will be outlined and the results of the FSD at the NPP Stade will be presented. It will be demonstrated that the achieved results express also the potential for dose reduction in operating nuclear power plants.

Keywords: Full System Decontamination, FSD, Decommissioning, PWR, CORD.

1. Introduction

The German PWR Stade was shut down in November 2003 after 31 years in operation. E.ON the owner of the NPP Stade (KKS) initiated early a program with regard to the decommissioning of its NPP. In 2003 a decontamination work shop was organized at Stade. All technologies available on the market were investigated until finally the Framatome ANP decontamination process HP/CORD UV of the CORD Family was selected as the most suited process with respect to references, decontamination efficiency and waste generation. The FSD performance was scheduled within a short period after shutdown of the plant and prior to the decommissioning activities. By performing FSD directly after shutdown, it can be ensured that all NPP systems are fully operational and, most important, NPP personnel with excellent system knowledge is still available. If FSD is performed after a shutdown period of several years or after safe enclosure, the effort on inspection and maintenance activities prior to the start of FSD will be extremely expensive and time consuming.

In the following sections, the principles of the CORD Family concept with focus on the HP/CORD UV process as applied at Stade as well as the FSD experience at Stade will be outlined.

In this context CORD (<u>C</u>hemical <u>O</u>xidation <u>R</u>eduction <u>D</u>econtamination) represents the chemical decontamination process while AMDA® stands for Automated Mobile Decontamination Appliance.

HP is used for permanganic acid as oxidizing agent and UV for the in-situ decomposition of the decontamination chemicals with ultraviolet light.

2. CORD Family Concept

Decontamination tasks all over the world demand extremely different requirements of a decontamination process. These requirements are subject to reactor type, base materials present in the system, system parameters and at least the specific decontamination target.

Therefore Framatome ANP developed in an early stage the CORD Family concept as a comprehensive decontamination concept. The CORD Family is a logistic approach, based on the idea that no decontamination process is capable to resolve or cover all worldwide existing decontamination needs with the desired results. This logistics approach is shown in Figure 1.

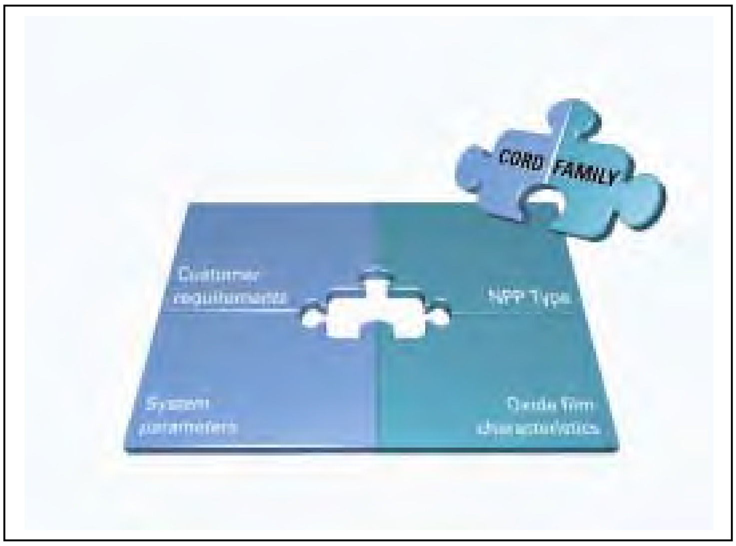

Figure 1: CORD Family Logistics

The decontamination processes that were developed by Framatome ANP follow the widely known advantages of the CORD Family concept:

- High material compatibility
- HP as oxidation agent
- One decontamination chemical for reduction and decontamination
- Entire decontamination is done with only one fill of water
- Regenerative process
- High decontamination factors for all reactor types and water chemistries
- Complete oxidation, in-situ decomposition of the decontamination acid to carbon dioxide
- Chelate-free waste (no decontamination chemicals in waste)
- Minimum waste generation.

The following table presents the most important processes of the CORD Family:

Table 1: Compilation of Most Important CORD Family Decontamination Processes

Worldwide PWR/BWR, stainless Steel	HP/CORD UV
Worldwide PWR RCP Internals	HP/CORD
Worldwide Decommissioning	HP/CORD D UV
Westinghouse NPPs Inconel 600-SG, FSD	HP/CORD N UV
Japan RHR Heat Exchangers (Cu-alloys)	CORD C UV
GE NPPs Auxiliary Systems, Carbon Steel	CORD CS UV
BWR Systems, Stainless Steel with $\geq$ 0,06% C	HP CORD 2000 UV
Worldwide Removal ALPHA Contamination	CORD ALPHA

The CORD Family Concept and the AMDA technology are the results of continuing development that makes Framatome ANP to one of the leading decontamination suppliers worldwide.

3. The HP/CORD® UV Concept

In general standard system decontaminations are performed by applying the HP/CORD UV process in connection with the Framatome ANP mobile decontamination equipment AMDA as external decontamination system.

Typical applications are:

- Decontamination of components
- Decontamination of systems or subsystems
- FSD

The HP/CORD UV process can be also adjusted for decontamination of systems with a mix of the base materials such as stainless /carbon steel.

Figure 2 below shows the logistics of the HP/CORD UV process.

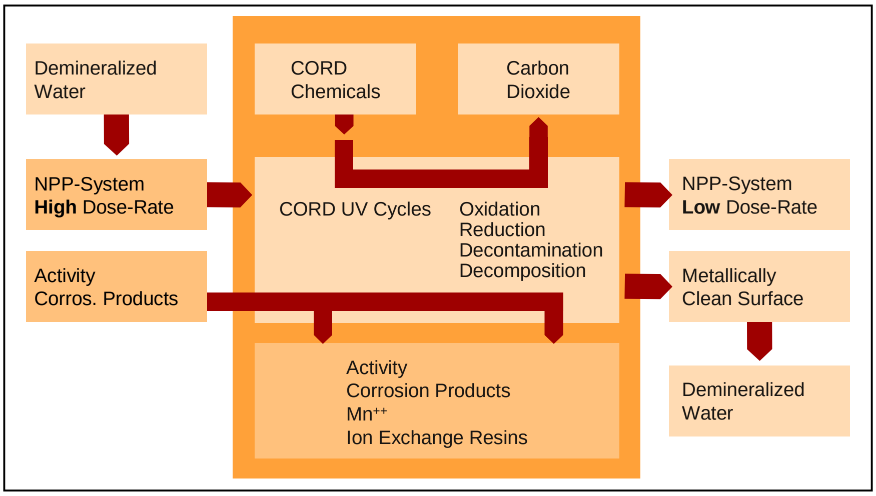

Figure 2: HP/CORD UV Logistics

The HP/CORD UV process as all state-of-the-art decontamination processes is applied as a multi-cycle process according to the decontamination targets. The whole process is done with only one fill of water. Each cycle is divided into the following steps:

Step 1: Oxidation with HP
Step 2: Reduction of HP with decontamination chemical
Step 3: Decontamination
Step 4: UV-decomposition of decontamination chemicals and clean up

Bypass purification is performed during the decontamination step to fix the dissolved activity and corrosion products on ion exchange resins. At the end of the decontamination step the in-situ UV-decomposition of the remaining decontamination chemicals take place. The decontamination chemicals are decomposed to water and carbon dioxide while purification of remaining activity and corrosion products is ongoing. By this procedure the system water reaches a purity that is close to demineralized water quality at the end of the cycle.

The HP/CORD UV process does not require a predetermined number of cycles to be performed. The number of cycles is part of the tailored concept according the given decontamination tasks and targets.

3. References for FSD

Framatome has worldwide experience with FSD not only for operating NPPs but also for decommissioning. Table 2 shows FSDs performed in NPPs that are still operating and Table 3 shows FSDs done prior to decommissioning.

Table 2: FSD References of Framatome ANP for NPPs in operation

NPP	**Country**	**Year**	**Reactor Type / Net Power**	**OEM**
Oskarshamn 1	Sweden	1994	BWR 442 MWe	ABB
Loviisa 2	Finland	1994	VVER 445 MWe	AEE
1 Fukushima 3	Japan	1997	BWR 760 MWe	GE/Toshiba
1 Fukushima 2	Japan	1998	BWR 760 MWe	GE/Toshiba
1 Fukushima 5	Japan	2000	BWR 760 MWe	GE/Toshiba
1 Fukushima 1	Japan	2001	BWR 460 MWe	GE/Toshiba

Table 3: FSD References of Framatome ANP prior to Decommissioning

NPP	**Country**	**Year**	**Reactor Type / Net Power**	**OEM**
BR3 Mol	Belgium	1991	PWR 10 MWe	Westinghouse
VAK Kahl	Germany	1992/93	BWR 16 MWe	GE/AEG
MZFR Karlsruhe	Germany	1995	PWR 55 MWe heavy water	Siemens
Würgassen	Germany	1997/98	BWR 670 MWe	Siemens
Haddam Neck	USA	1998	PWR 565 MWe	Westinghouse
Lingen	Germany	2001	BWR 240 MWe	GE/AEG
Caorso	Italy	2004	BWR 870 MWe	GE
Trino	Italy	2004	PWR 250 MWe	Westinghouse
Stade	Germany	2004/05	PWR 680 MWe	Siemens

4. FSD at the NPP Stade

4.1 Decontamination Targets

The targets for the FSD are summarized as below:

- Maximum reduction of activity inventory of Steam Generators (SG) to facilitate further decommissioning with regard to man-Sievert savings and to free release of materials
- Maximum reduction of ambient dose in plant working areas
- No significant change of Gamma/ALPHA ratio

4.2 Engineering

The overall project was split into 3 sections:

Section 1: Study for definition of process engineering and decontamination approach
Section 2: Preparation of application procedures
Section 3: Onsite performance of decontamination

All activities of the FSD were planned and performed within a close partnership between the project team of the plant operator Stade and Framatome ANP. The scope split was defined as given in Table 4:

Table 4: Scope Split for FSD at NPP Stade

NPP Stade	Framatome ANP
	Overall concept
Concept approval	
Engineering of KKS system technology	Overall Engineering including HP/CORD UV process adaptation
System modification ➢ Design ➢ Performance	Temporary external decontamination equipment a) AMDA component requirements (Framatome ANP decontamination equipment) b) Design and supply of additional decon equipment
Performance ➢ Operation of KKS Systems ➢ Radiation protection ➢ Chemical and gross gamma measurement ➢ Processing of ion exchange resins	Performance ➢ AMDA delivery and installation on site ➢ On site performance (4 decon cycles) ➢ Chemical process control ➢ Delivery of decontamination chemicals

4.3 Decontamination Flowpath

The PWR Stade is a 4 loop design and was 30 years in operation (1972 – 2003). The FSD was performed a short time after the shutdown to facilitate the upcoming decommissioning activities.

The FSD included the following main systems and components, as shown in Figure 3:

- Reactor pressure vessel (RPV) without the fuel but with RPV internals
- Pressurizer
- Primary system including all 4 loops, reactor coolant pumps (RCP) and steam generators (SG)
- Residual Heat Removal System (RHR)
- Volume Control System (VCS)
- Degasifier
- Reactor Water Clean Up System (RWCU)
- Parts of Emergency Injection System

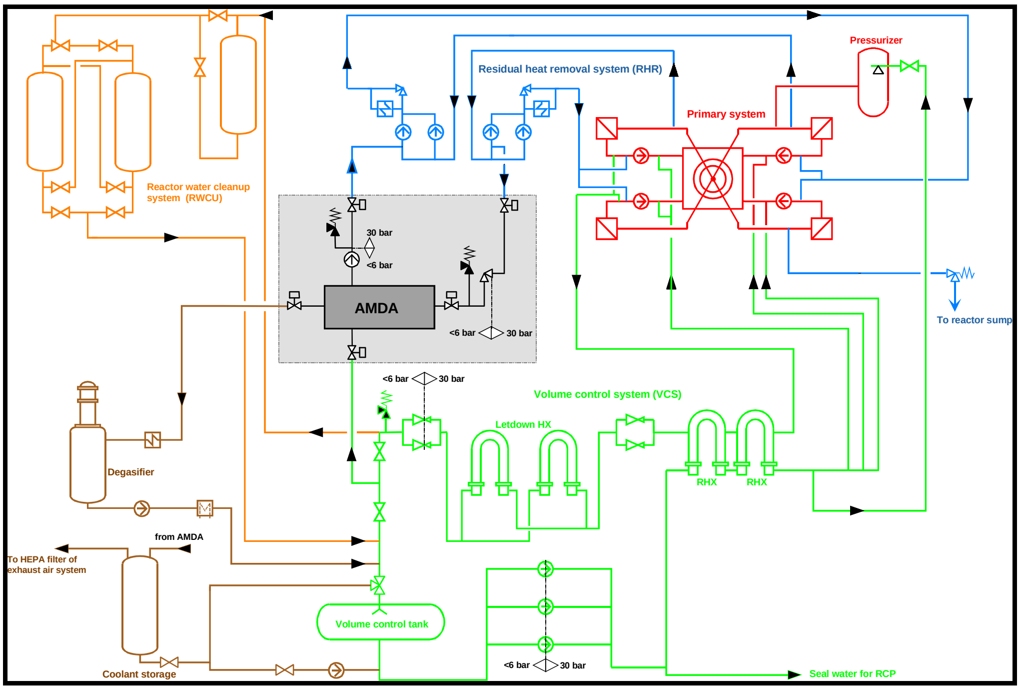

Figure 3: Principle Flow Diagram for FSD at Stade

The total volume of the systems included into the decontamination flowpath was approximately 310 m³ (81893 gal). The total surface area was approximately 17000 m² (183000 ft²). Table 5 breaks down the surface areas in relation to the main base materials.

Table 5: Material and Surface Characteristics of Decontamination Flowpath

		Area (approx. values)	
Base material	**System**	**m²**	**ft²**
Incoloy 800	Steam Generator (SG)	12000	129000
Austenitic weld cladding	SG channel head, loops, RCP	1000	10700
Austenitic CrNi-steel	Service and auxiliary systems	4000	43000

4.4 Process Engineering

As shown in the principle flow diagram (Figure 3), FSD was performed by operation of NPP systems. In addition to the NPP systems included into the decontamination flowpath, the following systems were involved as support systems:

- Chemical injection system
- Cooling system for RHR coolers
- Coolant storage system
- Exhaust air system
- Plant drainage system
- Resin storage tanks of RWCU

The AMDA as additional external decontamination equipment was installed for HP injection and as bypass for purification and in-situ UV-decomposition. No NPP filters of the RWCU were used for purification. These filters were empty and were part of the decontamination flowpath. The exhausted ion exchange resins were transferred to the NPP resin storage tanks.

The operational pressure requirement of a minimum of 30 bars for the RCPs was ensured by nitrogen injection into the pressurizer with a nitrogen compressor. All 4 RCPs were in operation and the residual heat was eliminated by operating both RHR coolers to ensure stable conditions for the process temperature. The main interface between plant systems and AMDA was installed at the RHR system. A pressure reduction skid was installed downstream of the RHR system interface to reduce the operating pressure of the AMDA decontamination flowpath from 30 bar to AMDA operating pressure of less than 6 bar. A high pressure pump skid at the end of the AMDA flowpath returned the decontamination solvent again with the required pressure of 30 bars into the RHR system.

5. Results

A total of 4 HP/CORD UV cycles were performed. The results are listed in Table 6 below.

Table 6: Results of the FSD at Stade

Cation and Activity Release	
Cation release in total	435 kg
Activity release in total	2,7 E13 Bq (730 Ci) with > 90% Co 60
Decontamination Factors	
DF overall	58*)
DF Primary circuit	74*)
DF SG tube section	160*)
DF auxiliary systems	38*)
DF ambient dose (DRF)	75*)
Gamma / ALPHA ratio	Before and after decontamination in range of 1000 - 4000

*) Final dose rate measurements were performed without shielding devices.
Actual decontamination factors are much higher

The decontamination result was also verified by visual inspection of the steam generators. Figure 4 and Figure 5 illustrate the excellent results.

Figure 4: SG Channel Head with Tube Sheet after Decontamination

Figure 5: SG Channel Head with Loop Line

Dissolved cations and activity were fixed on a total of 15.4 m³ ion exchange resins. The resins were transferred to the NPP spent resin storage tanks of the RWCU system. More than 70% of the total ion exchange resins was generated by primary waste namely by the dissolved corrosion products.

A comparison of resin waste generation with NP processes i.e. oxidation with potassium permanganate and nitric acid such as LOMI or CanDerem demonstrates clearly the big advantage of the HP/CORD UV process.

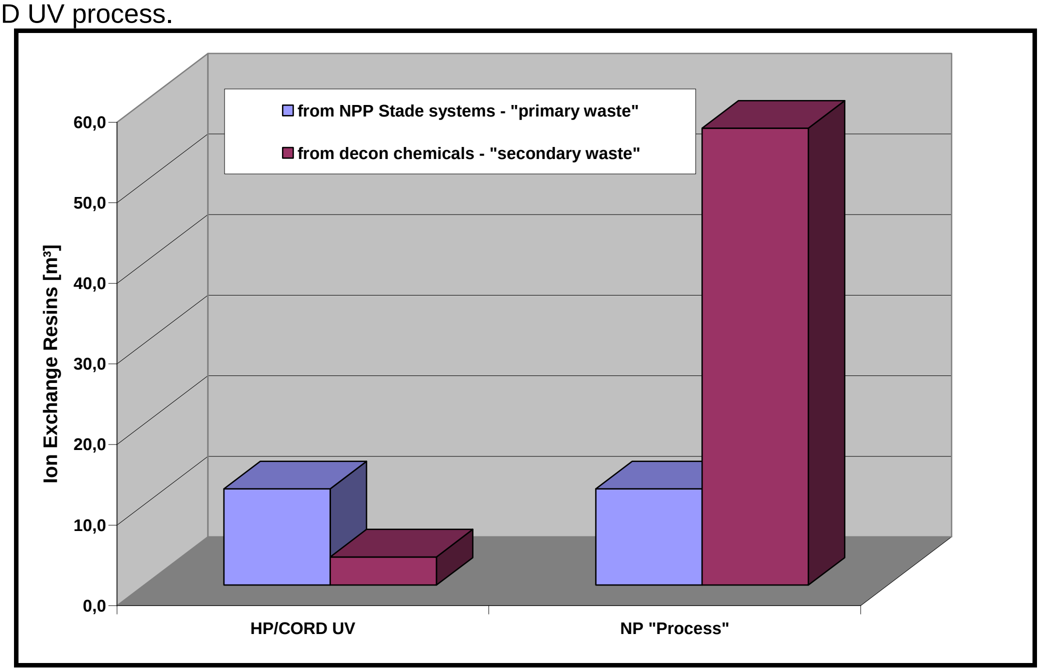

Figure 6: Waste Comparison HP/CORD UV and NP-Processes for FSD Stade

6. Conclusions

The FSD at the PWR Stade has shown that the HP/CORD UV process delivers excellent results in primary and in auxiliary systems. All decontamination targets as defined in Section 4.1 were met. Remarkable is the significant ambient dose reduction of 75 expressed by the ambient dose reduction factor (DRF). This extremely high DRF, no other decontamination application came even close, will result in high cost-benefit reductions for further decommissioning activities at Stade.

The decontamination factors listed in the Table 6 were calculated based on non-shielded measurements. This means that the remaining dose is predominantly from background radiation from smaller piping such as drain or vent lines which were not part of the decontamination flowpath.

It should also be noted that such complex decontaminations can only be successfully performed with good cooperation between customer and decontamination service company.

The results show that the integration of primary and auxiliary systems in the decontamination flowpath is extremely important for decommissioning.

In any case FSD should take place as soon as possible after shutdown to ensure availability of operational staff with a high level of system knowledge and also to ensure the unrestricted use and operational function of the NPP systems. This will ensure minimization of inspection and maintenance activities.

The applied HP/CORD UV process is not a special decontamination process for decommissioning but is a standard decontamination process for NPPs in operation.

The FSD at Stade has again demonstrated that HP/CORD UV – AMDA technology is perfectly qualified for FSD in operating NPPs. The resulting decontamination factors (DF) on the material surfaces as well as the ambient dose reduction factors (DRF) indicate clearly the advantage of a FSD in operating NPPs. Such FSD will result in extremely high personal dose rate savings.