Full System Decontamination – Sustainable Dose Reduction for Operating Nuclear Power Plants

Christoph Stiepani
AREVA NP GmbH, Paul-Gossen-Straße 100, Erlangen, 91052 Germany,
christoph.stiepani@areva.com

1 Introduction

Minimization of radiation exposure for the operational and outage personnel is one of the major indicators for safe operation of a NPP. This is reflected in the application of the ALARA principle (As Low As Reasonably Achievable).

The chemical decontamination of components and/or systems up to a FSD (Full System Decontamination) is accepted as effective measure. Regulatory bodies consider the chemical decontamination very positive and therefore approval / release for following activities are facilitated and sped up either for operating plants or during decommissioning.

The dose reductions by performing chemical decontamination prior to repair or inspection activities, as well as FSD prior to decommissioning are accepted worldwide.

This paper describes a concept for sustainable dose reduction with a FSD based on AREVA decontamination process, HP/CORD® UV (Chemical Oxidation Reduction Decontamination) in combination with adjustments to primary coolant chemistry, such as Zinc injection.

Especially with respect to life time extensions on operating plants, where dose reduction plays key role, this concept ensures that the health physics requirements can be met.

It will be demonstrated that this is a value added concept based on the application of reliable and qualified technologies such as:

- HP/CORD UV
- AMDA™ (Automated Mobile Decontamination Appliance)
- Zn-injection

2 AREVAs Concept for Sustainable Dose Reduction

AREVAs concept for the sustainable dose reduction is based on proven technologies. In **Figure 1** the overall concept is shown, with FSD as major point in the overall concept.

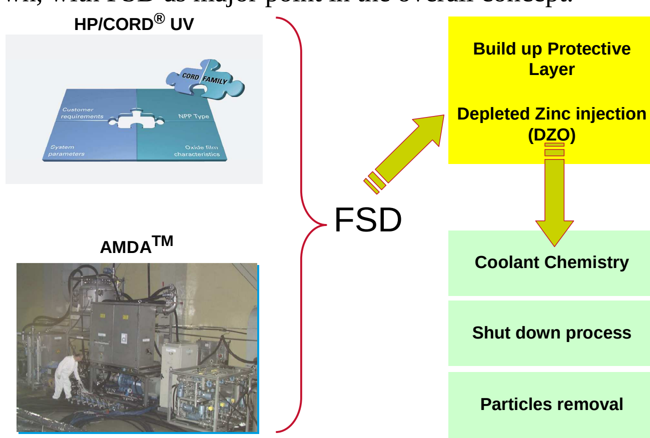

Figure 1: AREVAs Concept for Sustainable Dose Reduction

The concept is based on the following proven technologies:

- Decontamination technology
  - Decontamination process HP/CORD UV
  - Decontamination technique (NPP system with decon equipment AMDA)
  - FSD experience prior to decommissioning and for operating NPPs
- Protective layer build up
  - References of new builds and for steam generator replacement
- Zinc injection
  - Implementation at Angra 2 before first criticality
  - Implementation after several cycles for operating NPPs worldwide

3 Frequent Asked Questions (FAQs) and Reservations on Chemical Decontamination

Chemical decontamination is today an accepted approach prior to inspections, repair / refurbishment activities and as part of component replacement. The target is to achieve a local dose reduction at the planned working area and only for the duration of the activities. Typical applications of chemical decontamination in BWRs and PWRs are shown in Table 1.

BWR	PWR
Recirc pumps	Reactor Coolant Pump (RCP)
RWCU (reactor water clean up system)	Reg. heat exchanger
RHR (residual heat removal system)	Volume control system (VCS)
Recirculation system	Pressurizer (PRZ) • for heater bundle replacement • For refurbishment on spray lines
Pool cooling systems	Steam Generator (water chamber)
FSD • Decommissioning • Operating NPPs	FSD • Decommissioning • Operating NPPs

Table 1: Typical applications for chemical decontaminations in BWRs and PWRs

Especially with respect to FSD for operating NPPs the following questions and reservations are given to AREVA:

- Available references
- Reproducibility of decontamination results
- Material compatibility
- Residues of decon chemicals
- Reliability of process engineering
- Waste generation
- Cost and time intensively
- Recontamination
- Overall integrity of the NPP

Since 1976 AREVA is performing decontamination worldwide covering all major NPP designs. Up today more than 500 applications were performed including 7 FSDs for operating NPPs and this helped to minimize the reservations.

4 AREVAs Decontamination Technology

4.1 The Principle of HP/CORD UV

The first chemical decontamination was performed by AEREVA in 1976 at German PWR Biblis A and B for RCP decontamination. Today decontamination is performed according to the applications listed in Table 1 and based on the experiences for decontaminations in operating NPPs and for decommissioning the decon concept was consequently further developed.

In Figure 2 the principle of HP/CORD UV is shown. HP/CORD UV represents a regenerative multi-cycle decon process. As first step the oxide layer containing nuclides are oxidative treated with Permanganic acid (HMnO4; “HP”). After the reduction step, the corrosion products and the nuclides are chemical dissolved. During the regenerative process the corrosion products and nuclides are transferred on ion exchange resins. At the end of the decon cycle Oxalic acid, as decon chemical, is decomposed photo catalytic to CO_2 and H_2O.

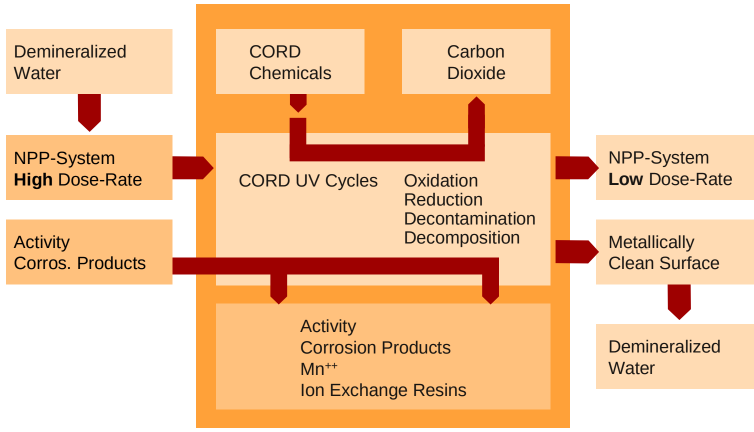

Figure 2: Principle of HP/CORD UV

The number of decon cycles is linked to the decontamination target, defined with the decon factor (DF) and is strongly depending on the oxide film characteristic (composition and layer thickness).

4.2 The Qualification of HP/CORD UV

The development started already in 1979, as shown in Table 2. First the material compatibility and the process engineering realization for the component decontamination was performed. After the first decontaminations further development until FSD was done, where the first FSD experiences were gained during FSD projects prior to decommissioning.

1979 - 1985	R&D and internal qualification
1985-1986	Qualification TÜV Bayern
1985	First decontamination in operating PWR (RCP decon)
1986	First decontamination in operating BWR (RWCU decon)
1988	Qualification TÜV Norddeutschland / TÜV Hannover
1987 - 1994	150 system decontaminations performed in Europe
1991	First FSD prior decommissioning in PWR (BR3 Mol, Belgium)
1993	First FSD prior decommissioning in BWR (VAK Kahl, Germany, Mol)
1994	First FSD for operating PWR (Loviisa 2, Finland)
1994	First FSD for operating BWR (Oskarshamn 1, Sweden)
1994 - 1997	Qualification for Japan for BWR and PWR (all designs)
1997 - 2001	Four FSDs in operating BWRs in Japan
2004 - 2008	Four FSD prior to decommissioning - German PWR Stade - German PWR Obrigheim - Swedish BWR Barsebaeck unit 1 & 2
2010	First FSD for sustainable dose reduction at German PWR Grafenrheinfeld
2011-2012	Three FSDs in operating BWRs in Japan planned Three FSDs for sustainable dose reduction at German PWRs in planning

Table 2: Overview on qualification of HP/CORD UV

5 AREVAs Concept for Sustainable Dose Reduction – Proven Technologies

The following chapter describes and gives examples for the proven technologies as base for the sustainable dose reduction concept.

5.1 Recontamination

The decontamination target is first at all to reduce the dose rates at components and systems to ensure low the personnel dose exposure during repair and inspections in accordance to ALARA principle. During the following operating cycle a recontamination occurs. The level and speed is depending mainly of the ratio surface decon area and removed activity inventory compared to the overall system.

This can be clearly demonstrated by the result of RCP decons (see **Figure 3**) and the FSD performed at Loviisa 2 (see **Figure 4**).

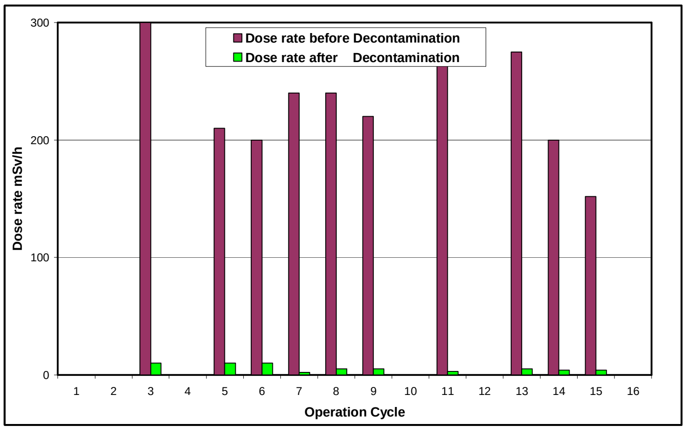

Figure 3: Dose rate before and after decontamination of RCP with high recontamination

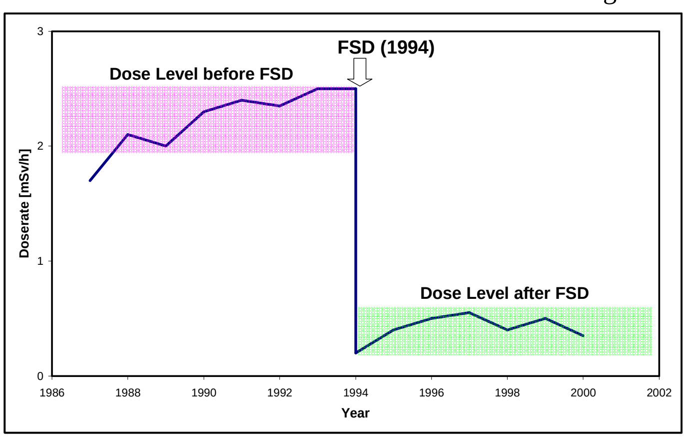

Figure 4: Dose rate before FSD Loviisa 2 and low recontamination after FSD

The following simplified formula can be applied:

As bigger the decon area and more activity inventory is removed, the recontamination level is lower and the speed is slower.

If additional measures on primary coolant chemistry improvements are implemented (see Figure 1) the positive effect on lower recontamination is increased. This can be demonstrated by the achieved results for the RHR decontamination in the Swedish BWR Oskarshamn 2. After this decontamination Zinc injection was performed. The real measurement data for the dose rates after the decontamination were much lower as expected by the calculations.

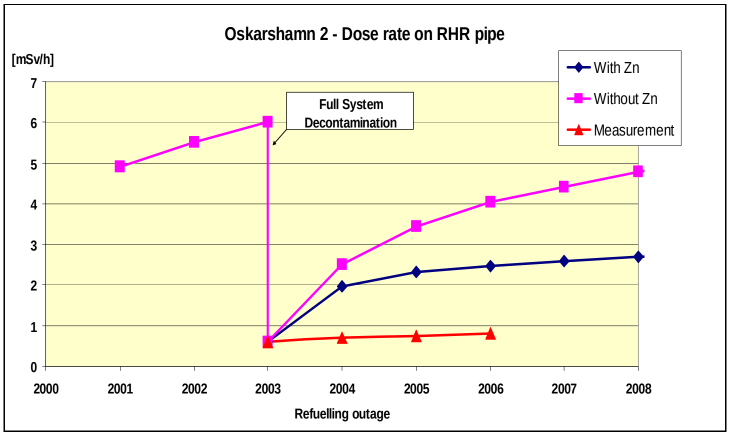

Figure 5: Low recontamination after RHR decontamination at Oskarshamn 2 HP/CORD UV and depleted Zinc injection

5.2 Worldwide AREVA References for FSDs in Operating NPPs and prior to Decommissioning

Table 3 and **Table 4** list AREVAs references for FSDs in operating NPPs and prior to decommissioning. Nearly every year a FSD was performed and the experiences were consequently implemented for the next one. These references demonstrate that FSD is a proven technology.

NPP	Country	Year	Design	OEM
Oskarshamn 1	Sweden	1994	BWR	ABB
Loviisa 2	Finland	1994	VVER	AEE
1 Fukushima 3	Japan	1997	BWR	GE/Toshiba
1 Fukushima 2	Japan	1998	BWR	GE/Toshiba
1 Fukushima 5	Japan	2000	BWR	GE/Toshiba
1 Fukushima 1	Japan	2001	BWR	GE/Toshiba
Grafenrheinfeld	Germany	2010	PWR	GE/Toshiba

Table 3: AREVA references for FSDs in operating NPPs

NPP	Country	Year	Design	OEM
BR3 Mol	Belgium	1991	PWR	Westinghouse
VAK Kahl	Germany	1992/93	BWR	GE/AEG
MZFR Karlsruhe	Germany	1995	PWR, D_2O	AREVA
Stade	Germany	2004/05	PWR	AREVA
Obrigheim	Germany	2006/07	PWR	AREVA
Barsebaeck 2	Sweden	2007	WR	ABB
Barsebaeck 1	Sweden	2008	WR	ABB

Table 4: AREVA references for FSDs prior to Decommissioning

5.2.1 FSD in Operating NPP Oskarshamn 1

The FSD was performed in 1994, means after 22 years of operation. Reason for FSD were the inspection and repair activities to performed on the bottom of the RPV. The FSD included the RPV, the RECIRC system, the RHR system and also the RWCU system. 99.5% of the activity inventory was removed with 4 cycles HP/CORD UV and a resin waste of only 2.1 m³ was generated. The dose rate at the RPV bottom was reduced from a level of 30 mSv/h to the extremely low level of 20 µSv/h. This reduction resulted in a DF > 1000. The ambient working dose at the RECIRC working area was reduced by a Factor of 30. Also the smearable contamination level after the FSD was very low with < 4 Bq/cm². Overall the FSD resulted on a personnel dose exposure saving of 20000 mSv.

Figure 6 expresses the benefit of a FSD. Due these low achieved dose and contamination levels the inspection and reapir activities were possible on the RPV bottom without sophisticated manipulator equipment.

Figure 6: Inspection of RPV after the FSD

5.2.2 FSD in Operating NPP Loviisa 2

Loviisa 2 is a PWR of the Russian type VVER-440, six-loop design with horizontal steam generators, and has been in commercial operation since the beginning of 1981. At Loviisa 2 the dose rate of the extensive primary circuit had remarkable increasing during the last years before the long outage scheduled for 1994 (see Figure 4) and this dose level was deemed to high for the planned large inspection and repair works. Due to the FSD decision many of dose requesting jobs were moved from outage 1993 to 1994, and even inspections from 1995 were done in advance in 1994. The FSD resulted in a high DF between 33 and 150. The ambient dose reduction factor was 16 (see dose rates before and after FSD in Figure 7). Overall 8000 mSv personnel dose were saved due to the FSD.

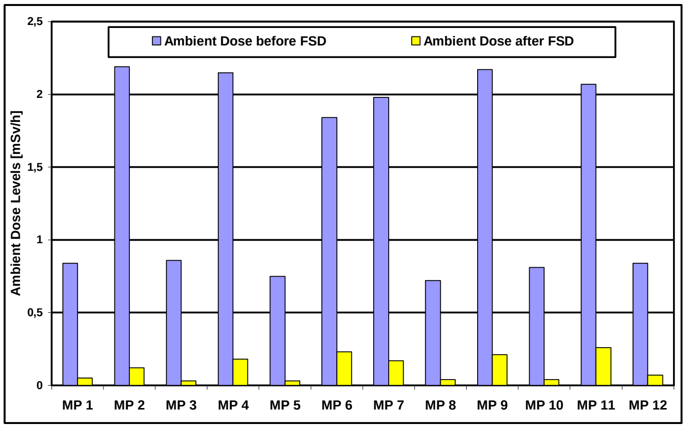

Figure 7: Ambient dose rates at Loviisa 2 before and after the FSD (average DRF 16)

The success of this FSD by a removal of approx. 99% of the activity inventory and with a very low recontamination rate is shown in (see Figure 4). This expresses the FSD as a powerful tool for a sustainable dose reduction tool.

5.2.3 FSDs prior to Decommissioning at NPPs Stade and Obrigheim

FSD prior to decommissioning is worldwide the most accepted approach for the dose reduction and to facilitate the decommissioning planning and performance. The FSDs at Stade and Obrigheim were performed based on a similar concept. **Figure 8** shows the excellent results achieved for the ambient dose reduction. On the right side of the figure there are areas shown where still interferences due to not decontaminated pipes are given. These pipes were planned to be removed first during the following decommissioning steps and so the low ambient dose rates as shown on left sides are also achieved overall.

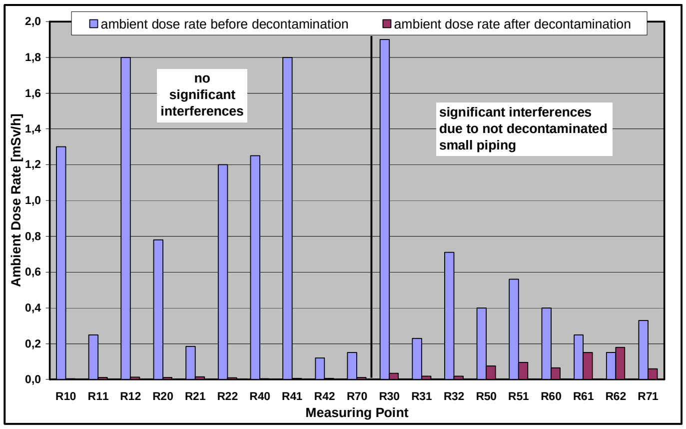

Figure 8: Ambient dose rate reduction with FSD at NPP Stade; overall DRF 120

The FSD concept Stade and all lesson learned were implemented consequently in the FSD at Obrigheim. By this approach the already excellent results of Stade were even exceeded. After four cycles of HP/CORD UV very low dose rates were achieved, as demonstrated in Figure 9.

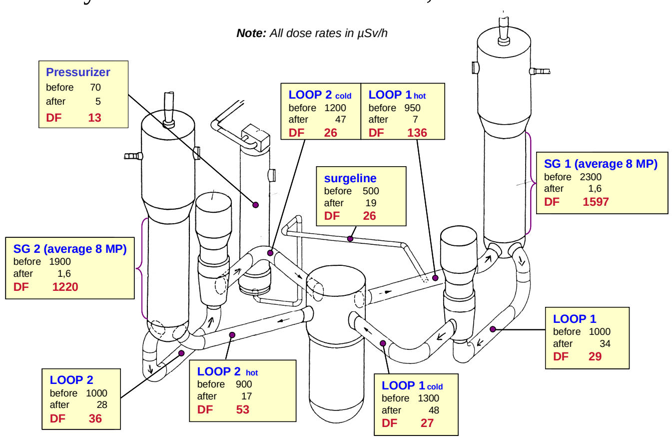

Figure 9: Dose rates before and after FSD for primary circuit Obrigheim

At NPP Obrigheim the Zinc injection was applied ruing the last operation cycles. The achieved low dose rates demonstrate that zinc injection has no influence on the decontamination efficiency of HP/CORD UV.

5.3 Personnel Dose Exposure Reduction due to FSD Application

Table 5 gives examples for dose savings based on customer data. These dose savings show also the high potential of FSD for minimization of personnel dose exposure.

NPP	FSD year	DF	Dose Savings [mSv]
Oskarshamn 1	1994	20 to 1000	20000
Loviisa 2	1994	14 to 153	> 8000
1 Fukushima 3	1997	43 to 72	70000
1 Fukushima 2	1998	68 to 108	140000
1 Fukushima 5	2000	35 to 83	50000

Table 5: Personnel dose exposure after FSD (customer data)

5.4 Experiences with Zinc Injection for Dose Reduction

The coolant chemistry has a significant influence on the dose build up and at the end on the personnel dose exposure. The Zinc injection minimizes and avoids the installation of nuclides in the oxide layer, with main focus on Co^{60}. The Zinc injection is done with depleted Zinc with Zn^{64} < 5%. The injection of DZO is worldwide an accepted approach and a qualified technology to reduce dose levels in operating NPPs.

The efficiency of dose reduction by applying Zinc injection for BWR and PWR can be demonstrated with Figure 10 and Figure 11.

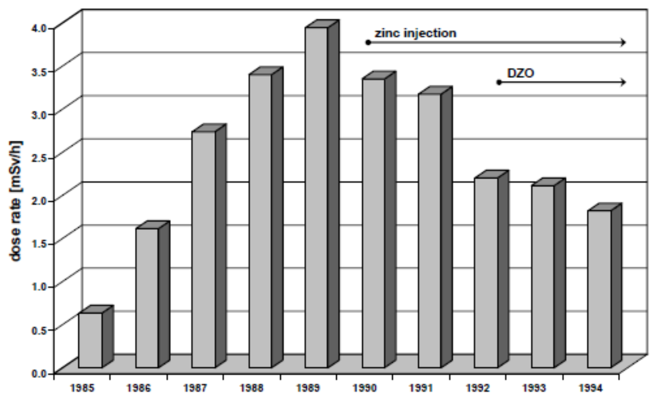

Figure 10: Dose reduction in BWR with Zinc injection

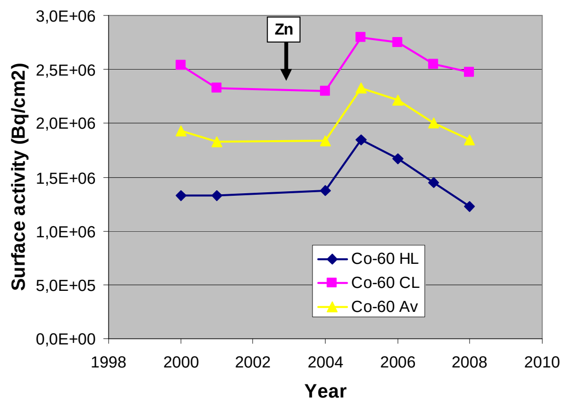

Figure 11: Dose reduction in PWR by applying Zinc injection; significant decrease of Co^{60} surface activity

The Zinc injection experience of Angra 2 demonstrates the potential for the sustainable dose reduction concept. Angra 2, a four-Loop PWR started operation in 2000. The Stellite inventory is much higher than as Konvoi design. The Zinc injection was performed during the commissioning phase, two days after frits criticality. By the Zinc injection the dose levels stays on a level comparable to the level of Konvoi. Detailed results were presented at ISOE conference in 2006.

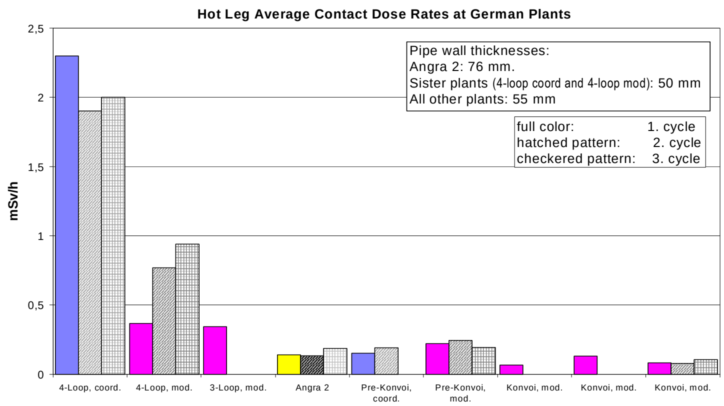

Figure 12: contact dose levels at hot loop; comparison of Angra 2 with other PWRs

6 Conclusion

AREVAs concept for sustainable dose reduction is basing on qualified technologies, as shown in Table 6. References for all technologies are available.

FSD is a qualified technology and mandatory for the success is here the combination and team play between:

- Decontamination process
- Process engineering
- Qualified personnel

Qualified personnel in this context mean the competence and experience. In addition the cooperation between NPP personnel and decontamination service personnel during planning and performance of the FSD is one of the important subjects.

Decontamination process	HP/CORD UV	• Leading technology • Worldwide references for all main NPP designs • Own developed process and further development • High DFs achievable • Reproducible results • High reliability • Lowest waste volume • Low recontamination
Process engineering	AMDA	• Process engineering experience for NPP systems in combination with AMDA for BWR and PWR • Long operation experience (> 30 years) • Own development • Modular design • Consequent application of ALARA principle • Monitoring of process parameter
Personnel	AREVA	• Experienced personnel (> 10 decontaminations per year) • Nearly every year one FSD • In-house competence for all areas • Competence in coolant chemistry
Coolant chemistry	Zinc injection	• Long experience • Excellent results for Angra 2 • Excellent results for operating BWRs and PWRs

Table 6: AREVAs concept for sustainable dose reduction – qualified technologies