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Primary System Decontamination of the German PWR Grafenrheinfeld – Process Application and Recontamination Experience

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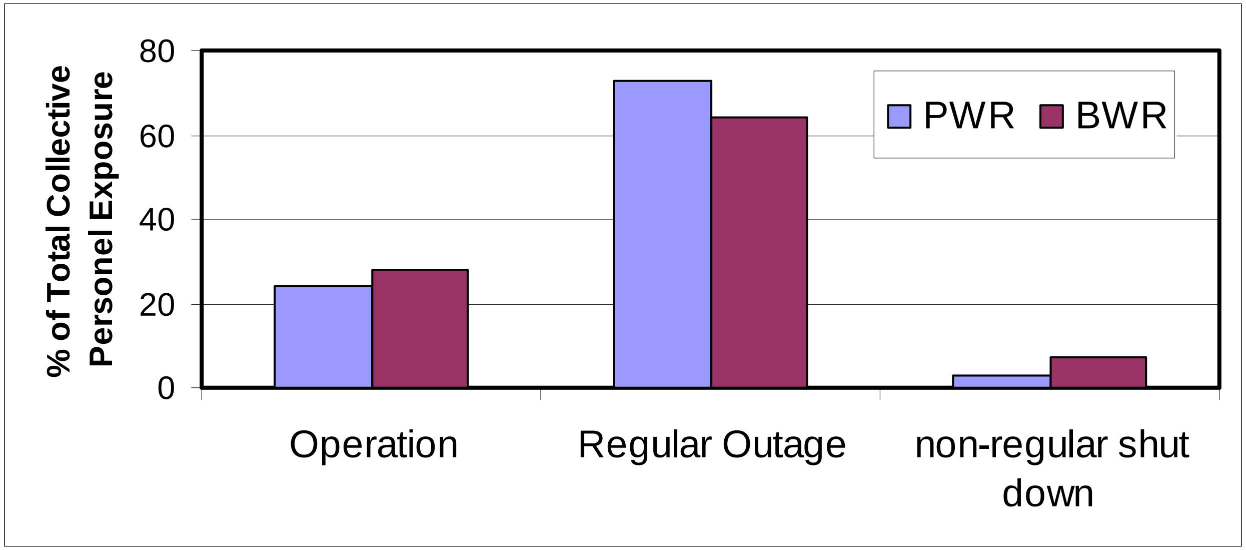
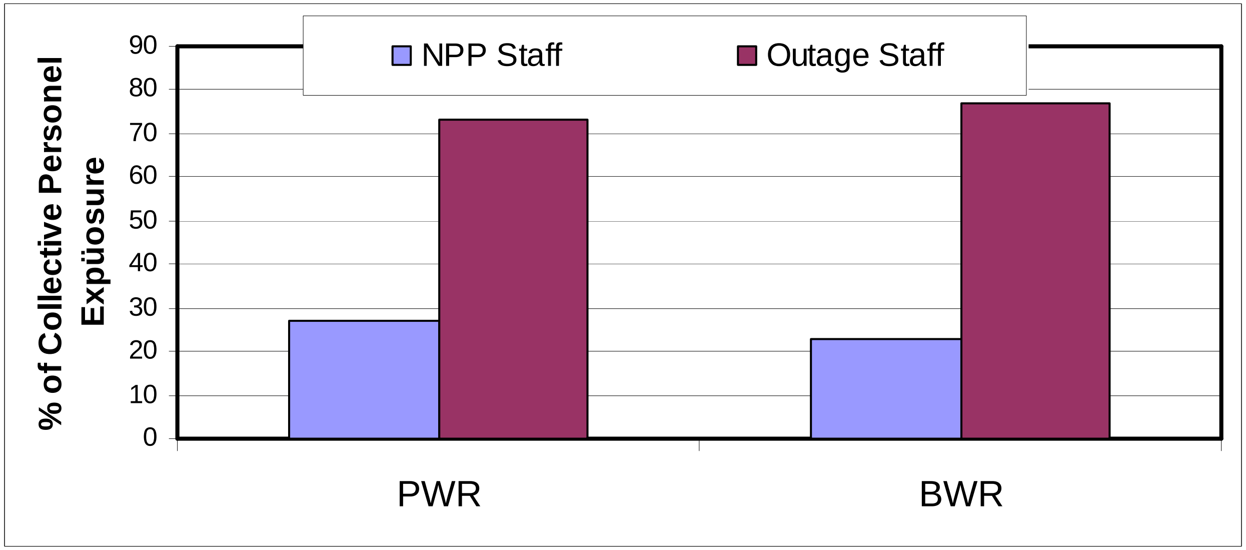
Content

- CRE trends and dose build up in LWRs
- Dose reduction concept with FSD
  - Application examples for FSD
  - Proven technologies
  - Example for FSD in BWR
- FSD in German PWR Grafenrheinfeld in 2010
  - Performance
  - Results
- Recontamination Expereince after FSD
- Summary

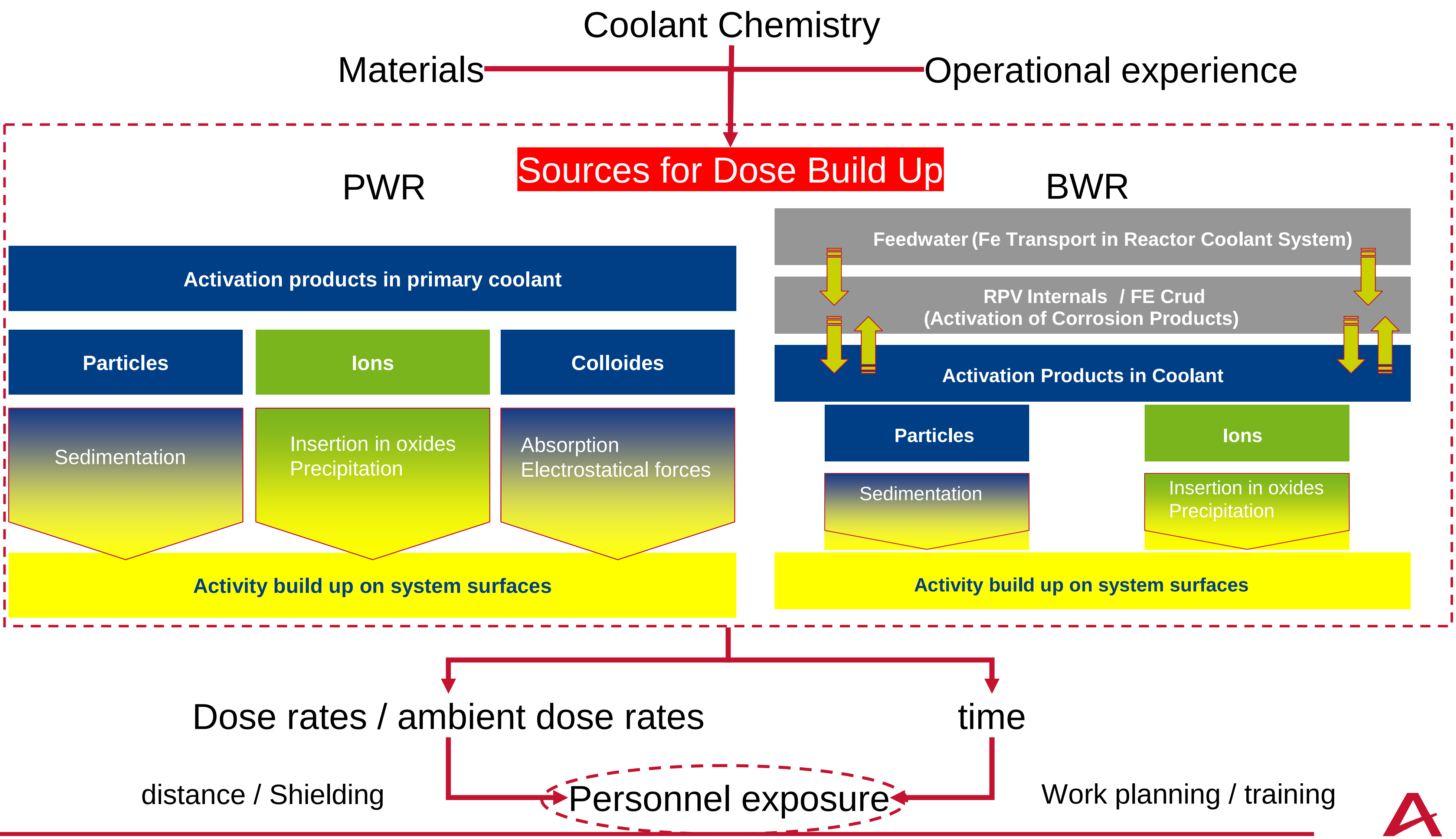
CRE Distribution in European LWRs





2006 ISOE Conference Essen; K. Schnuer

Base for Dose Reduction Plans
ALARA Principle



Why dose reduction? - Countermeasures

- **ALARA Principle**
- **Requirements of regulatory bodies**
- **CRE as Performance Indicator**
- **Countermeasures – Dose Reduction Plan**
  - **Reactor coolant chemistry**
  - **Optimization of start up and shut down procedures**
  - **Outage optimization**
    - Task optimization
    - Specialist – operating personnel
    - Manipulator technology
  - **Installation of permanent shielding**
  - **Decontamination for local dose reduction to perform task**

Example for Collective Dose Exposure Savings (Customer Data)

BR3 Mol (PWR)	**FSD (Decommissioning)**	**7500 mSv**
VAK Kahl (BWR)	**FSD (Decommissioning)**	**2200 mSv**
Oskarshamn 1 (BWR)	**FSD (CRDs repair)**	**20000 mSv**
Japan (BWR)	**5 FSDs (core shroud replacement)**	**up to 140000 mSv**
Conneticut Yankee	**FSD (Decommissioning)**	**> 10000 mSv**
Leibstadt (BWR)	**decon recirc pumps**	**1200 mSv**
Biblis (PWR)	**decon volume control system**	**900 mSv**
Grafenrheinfeld (PWR)	**FSD (suistainable dose reduction)**	**> ~4900 mSv*)**

*) preliminary estimates for savings for outage direct after FSD and after 1 cycle

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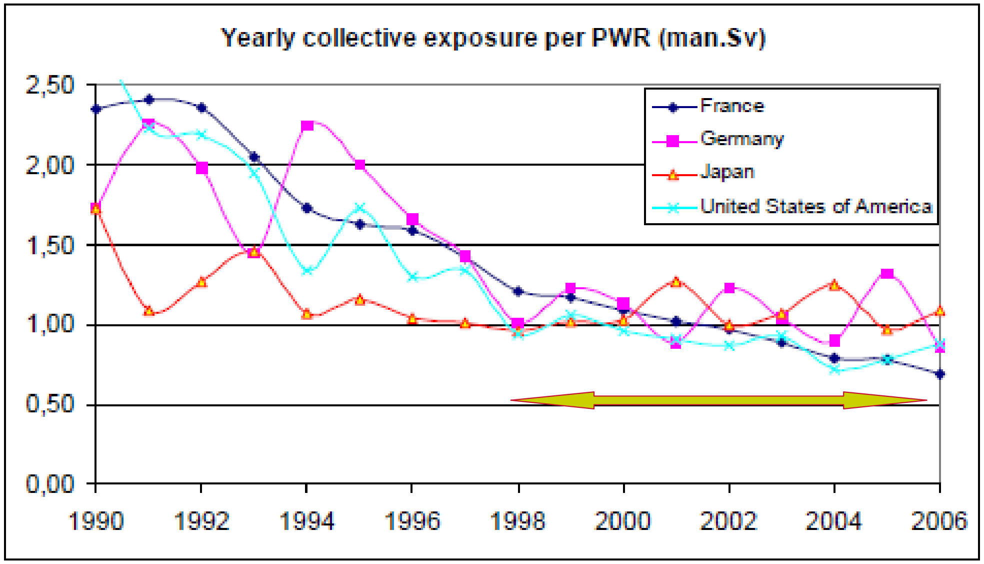
Driver for FSD

- **Dose reduction plans implemented**
- **Countermeasures successful**
  - **Material concept**
  - **Coolant chemistry**
    - high optimization grade
    - Effect on dose reduction over years
  - **Outage planning**
    - high optimization grade
    - Permanent shielding problem with loads on structure
  - **Chemical decontamination**
    - Approved procedure for local dose reduction
    - Low Recontamination during next operation cycles

Average CRE for PWRs Worldwide

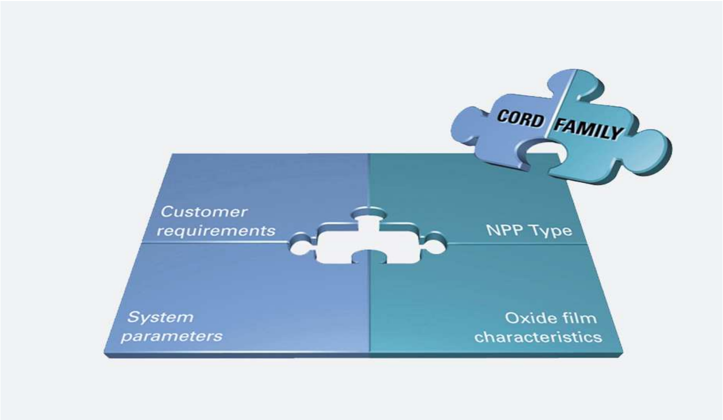


Achieved levels of CRE can be further significant and fast decreased:

Concept for fast and sustainable dose reduction with FSD

Concept for Sustainable Dose Reduction based on Proven Technologies

HP/CORD® UV



AMDA™

FSD

Build up Protective Layer

DZO

Coolant Chemistry

Shut down process

particles removal

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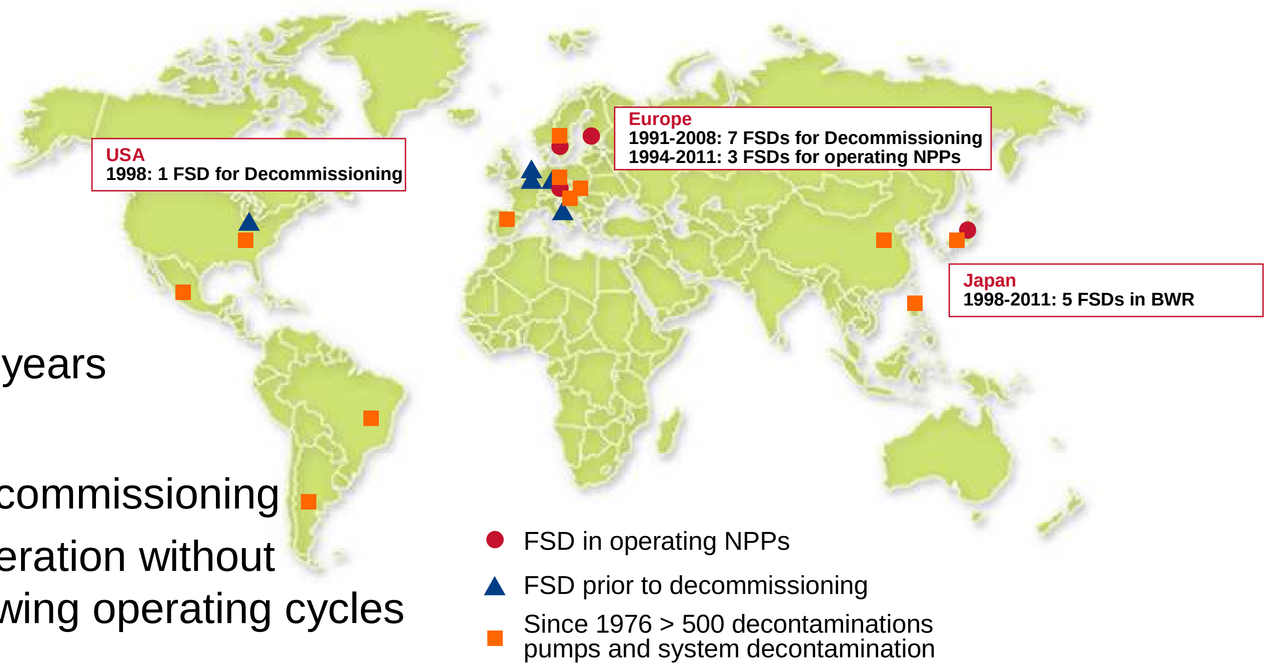
HP/CORD UV und AMDA
Proven and Reliable Decontamination Technology

- **Conzept is based on proven technologies**
  - **HP/CORD UV**
    - References
    - High material compatibility
    - Low waste generation
  - **AMDA**
    - Proofen and reliable since 30 years
  - **FSD**
    - References since **1991** for decommissioning
    - References since **1994** for operation without negative experiences for following operating cycles
    - High system integrity



- **Protective layer build up**
  - **New builds and for SG replacement**

» **World wide FSD references for BWR, PWR und PHWR in all major NPP designs**

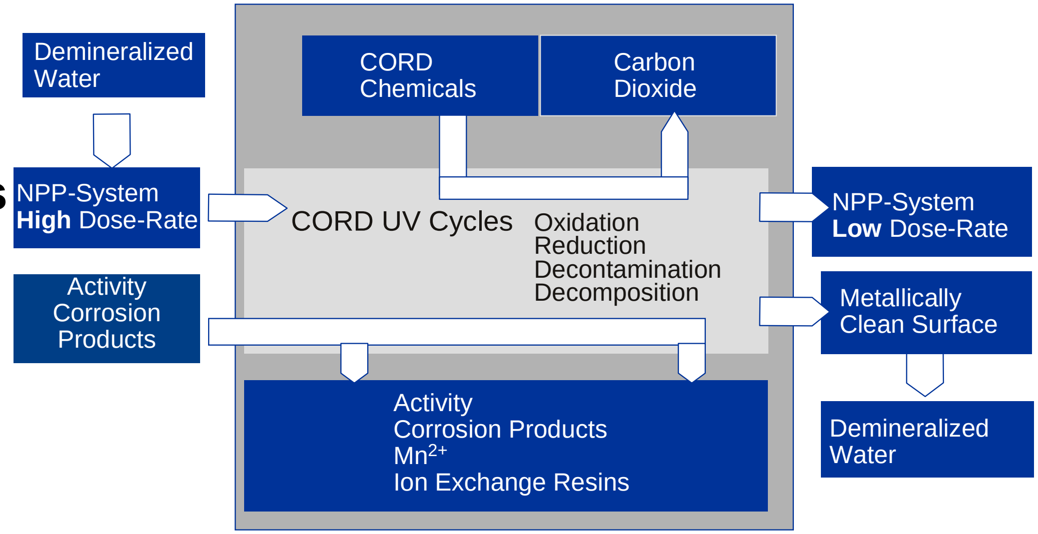
- **Zinc-Injection**
  - **Worldwide references (Angra 2; PWR and BWR)**

Application Fields for FSD

- **Sustainable Dose reduction if personnel exposure is above defined levels (INPO / WANO levels)**
- **Sustainable dose reduction as part of life time extension program and/or power upgrade**
- **Dose reduction prior to major refurbishment activities**
- **Dose reduction prior to SG-replacement**
  - **SG with low dose for dismantling activities**
  - **Less effort for Health Physics and Shielding**
  - **Low effort for component final disposal storage or recycling**
  - **Double win:**
    - SG replacement easier with low dose rates
    - Start up phase for protection
    - Sustainable dose reduction
- **Dose reduction for core internal replacement**
  - **In combination with material concept removal of activity inventory**
  - **Low sustainable dose after FSD**

HP/CORD UV – Main Figures

- **Soft Decontamination process with high material compatibility**
- **Worldwide references in all major designs**
  - **> 500 decontaminations since 1976**
- **Reproducible high Decon Factors**
- **Multi-step, multi-cycle process**
- **No CMR chemicals**
- **Regenerative process**
  - **Activity inventory and corrosion products put on ion exchange resins**
- **Low waste generation**
  - **Decon solvent oxalic acid is decomposed to CO_2 and H_2O**



World wide decontamination applications

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Often asked Questions – Oppositions against FSD

CORD Family

References?	**>500 Decontaminations since 1976** **18 FSDs (8 for operating NPPs)**
Reproducibility?	**proven; detailed information available**
Material damages?	**Qualified processes** **high material compatibility verified by independent agencies** **and verified by long term operation after decontamination without negaitve effects (references)**
Residues of decon chemcials?	**Continuous by-pass purification and UV decomposition step during decontamination** **Flushing program for dead ends**
Reliability of process engineering?	**Proven NPP system engineering and AMDA technology**
Radioactive waste?	**Minimum waste by dissolution of oxides** **secondary waste of decon chemicals minimized by UV decomposition step**
Recontamination?	**As lower as bigger the decon area and the removed activity inventory**
NPP integrity after re-start?	**Proven by material compatibility evaluation and field experience (references):** **NPP OKG 1 and Loviisa 2 as also the 4 Japan BWRs are in operation without problems;** **latest reference FSD in German PWR Grafenrheinfeld in 2010**

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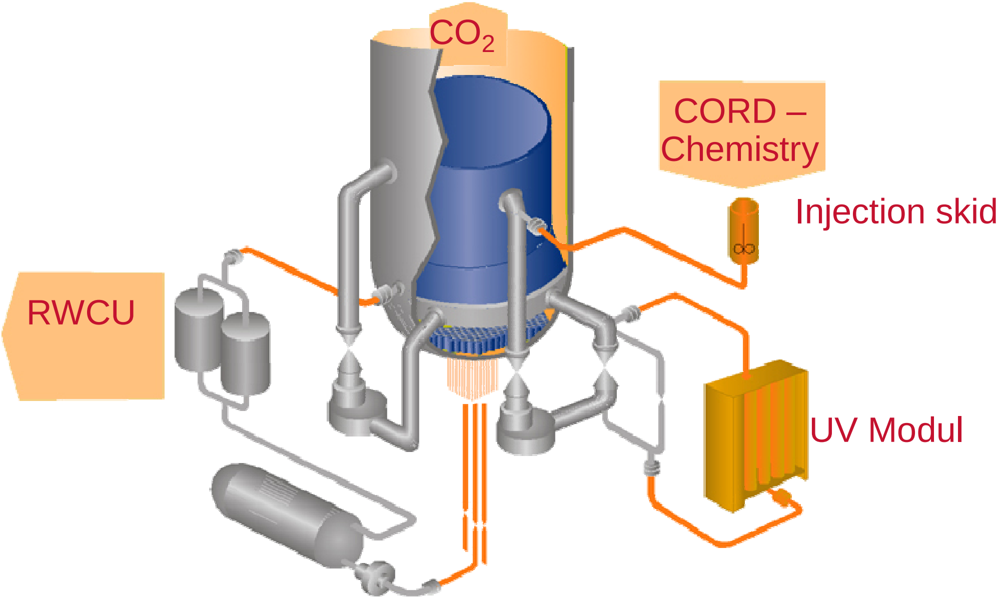
Proven Technology
FSD OKG 1, 1994

2,3 E12 Bq Aktivity and 30kg corrosion products removed
IX-resin waste: 2,5 m³
Man-Rem Savings: 20000 mSv (customer data)
DF 20 until > 1000; DRF > 10
Dose rate RPV bottom after FSD: 20 µSvh
Smearable contamination < 4 Bq/cm²

RPV Inspection after Decontamination



Oskarshamn 1 – Decontamination Principle

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Proven Technology
5 FSDs in Japanese BWR for Core Shroud Replacement
Reproducible Results

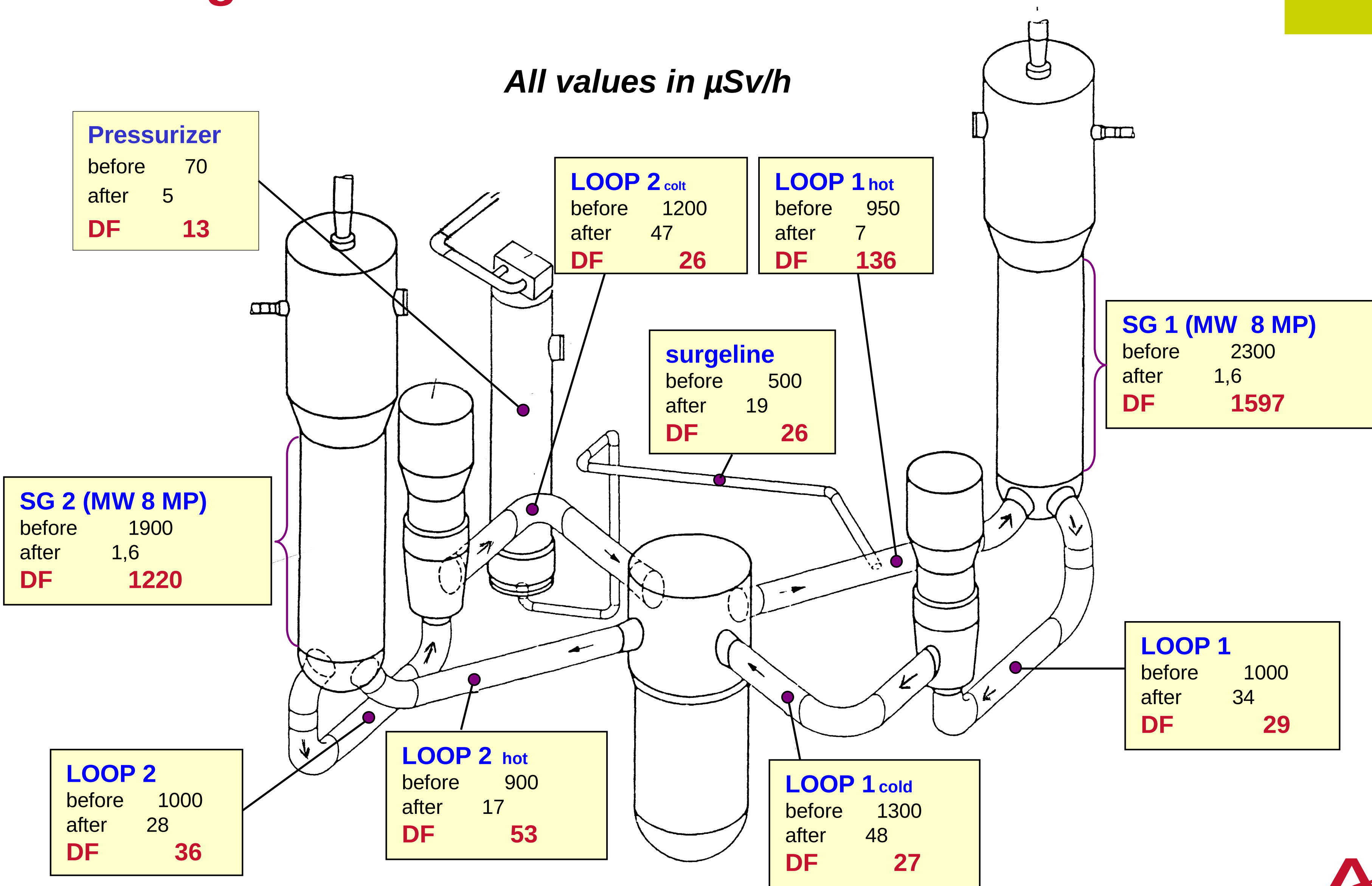
2 FSDs were planned for 2012 – due to Fukushima cancelled or postponed

	1997	1998	2000	2001	2011
Activity release	1.03 E13 Bq	9.98 E12 Bq	7.55 E12 Bq	8.32 E12 Bq	8.34 E12 Bq
DF RPV bottom	43	108	35	60	42
DF Recirc	46	68	83	88	37
DF Nuclide specific	72	308	435	196	—
DF RHR/CUW (C-Steel)	—	—	28	13	7 **(hot spots)**

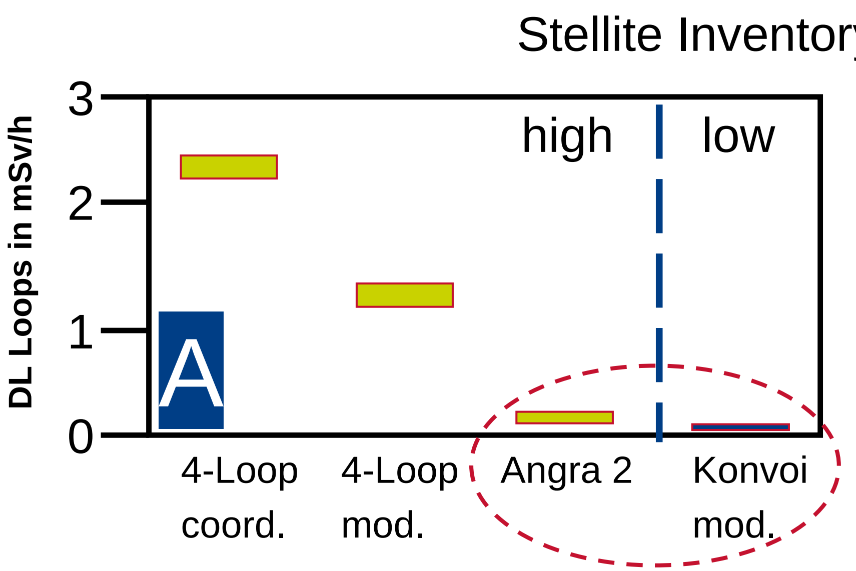
► IX-resin waste between 4 und 5 m³, depending on decon area

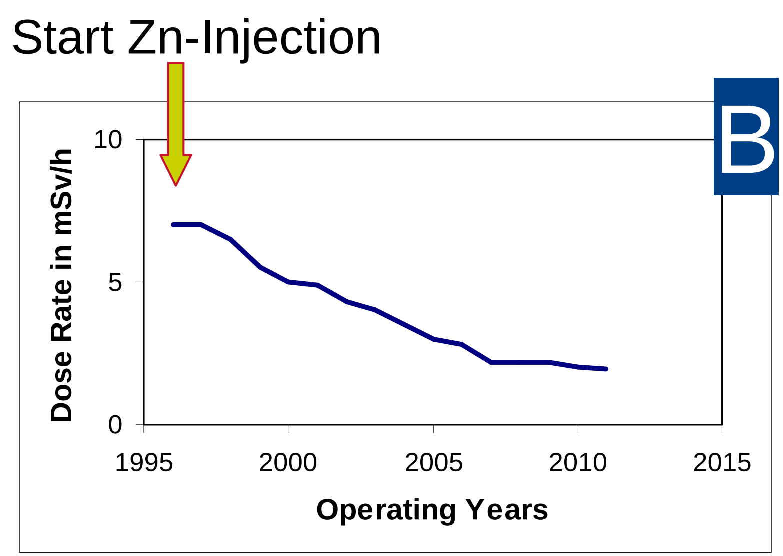
Proven Technology
FSD Obrigheim - Excellent Dose Reduction Values

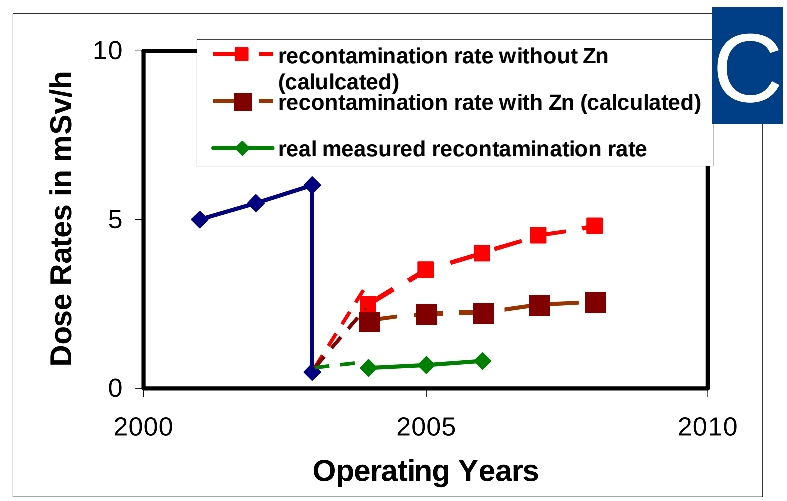
All values in µSv/h



Proven Technology
Zinc Injection – Effective Dose Reduction







A Angra 2 Zn Injection before 1st criticality
low dose rates on level as Konvoi with low stellites

B Zn injection in operating NPPs
(German PWR as example

C Decontamination and Zinc Injection; fastest and sustainable dose reduction
(Swedish BWR as example)

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NPP Grafenrheinfeld

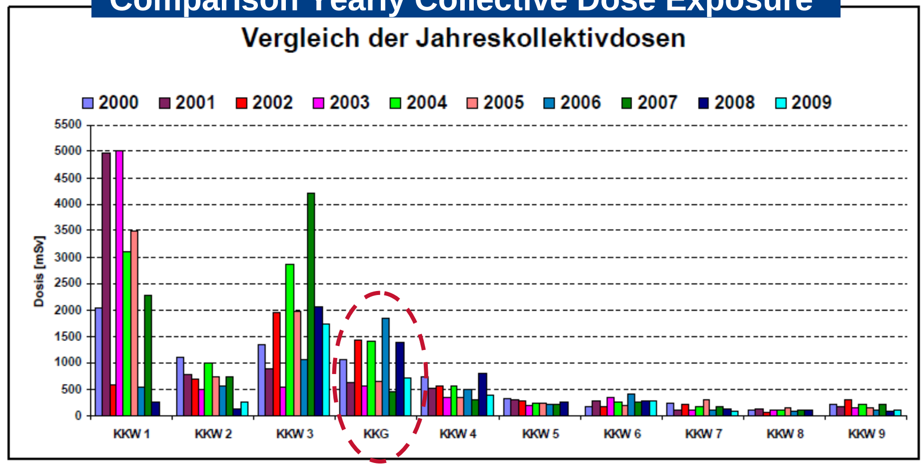
- PWR, 4-Loop
- Net Power: 1345 MWe
- NSSS supplier: Siemens KWU
- Start commercial operation: 1982
- Coolant chemistry:
  - Modified chemistry (B/Li)
  - in 2004 start of Zn-injection

copyright@E.ON NPP Grafenrheinfeld

FSD Grafenrheinfeld
Motivation and Targets of E.ON

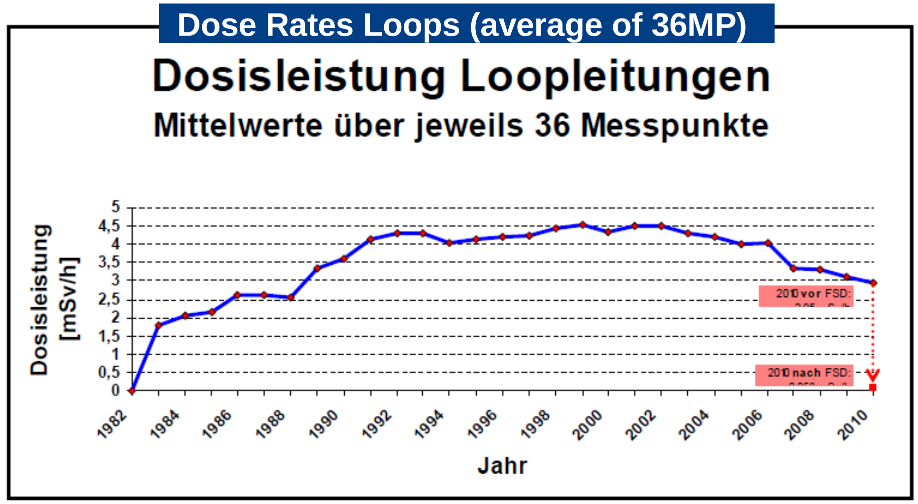
- **ALARA Principle**
  - **Further improvement of dose rate situation for operation and outage personnel**
  - **Dose savings estimation / target for 2010 to 2014: 5350 mSv expected (= 260 man-year dose)**
  - **Lower dose rates for future refurbishment activities**
- **achieve dose levels below international standards**
- **to meet WANO performance indicators**
- **E.ON to set new technological standard**
- **improve resource availability, e.g. as for NDE experts**

Comparison Yearly Collective Dose Exposure



Ref.: E.ON NPP Grafenrheinfeld

Dose Rates Loops (average of 36MP)



before FSD

after FSD

Ref.: E.ON NPP Grafenrheinfeld

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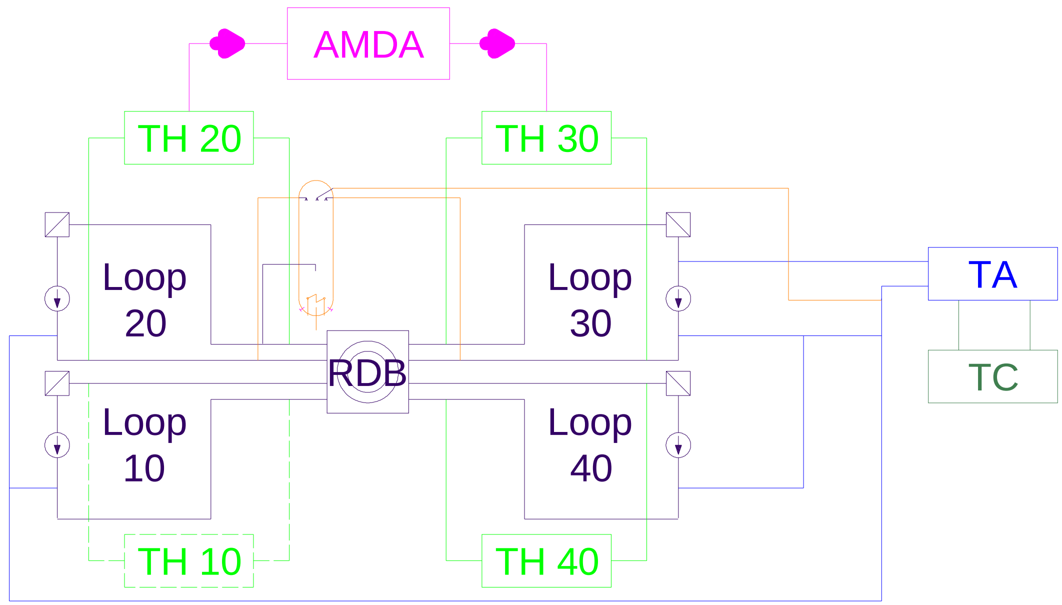
FSD Grafenrheinfeld Decontamination Concept

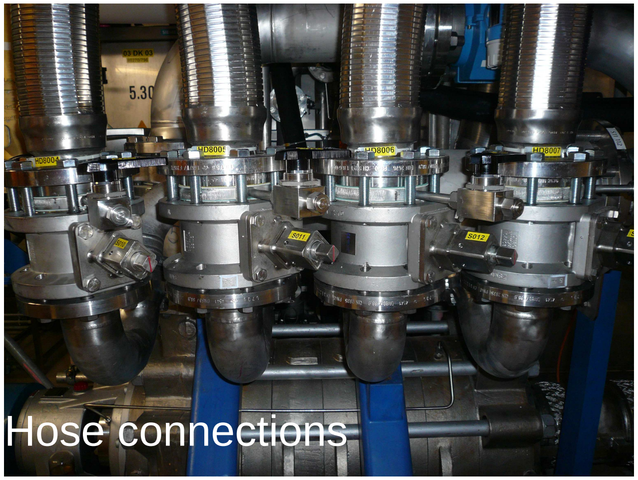
- **Decon process**
  - **HP/CORD UV**
- **NPP system and AMDA**
- **Decon Area**
  - **Primary circuit**
  - **3 Residual Heat Removal systems RHR (TH20 – TH30 – TH40)**
  - **Volume control system (VCS)**
  - **Coolant clean-up (RWCU)**
- **RHR system TH10 decon after FSD**
- **Main characteristics:**
  - **Volume: ~ 520 m³**
  - **Surface:**
    - ~ 21544 m² (SG tubing I 800)
    - ~ 3700 m² (Stainless steel - Austenite)



FSD Grafenrheinfeld
Process Engineering – Main Characteristics

- RPV defueled and CRDs removed
- Coolant deborated
- Recirculation
  - Primary circuit: RCPs
  - RHR system: RHR pumps
  - VCS: temp. installed pump
- RCP (hydrostatic sealing)
  - Modification on sealing
  - Temp. installed sealing water supply with demin. Water
- Process temperature: up to 95℃
  - Heat up with RCPs
  - Control via RHR coolers
- Process pressure: approx. 22 bar
  - Pressurizer hydraulic full
  - Control via pressure tank in RHR system

- AMDA connection at RHR systems
  - Temporary installed connections with hoses
- AMDA tasks:
  - Chemical injection
  - Mechanical filtration
  - Ion exchange clean up
  - UV-decomposition of decon solvent



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FSD Grafenrheinfeld
Actual Decontamination Performance

- **During decontamination in 1st cycle unexpected high mobilization of corrosion products and activity with following effects**
  - **Particles with high dose rates transferred in dead ends and areas with low velocity causing higher ambient dose rates**
  - **Particles easily to remove by flushing**
- **Chemical decon concept modified during site application**
- **Modification of planned flushing program for dead ends with higher dose rates in cooperation between E.ON and AREVA**

Finally a high decontamination factor was achieved
and the operation for new protective layer during start up was performed without problems.

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FSD Grafenrheinfeld
Dose Rates (before and after FSD) and DF

Area	MP (contractual)	Average Dose Rates before mSv/h	after mSv/h	DF
SG tubing area	16	0.102	0.002	67
Pressurizer, spraylines, surgeline	12	3.366	0.097	42
Primary loops	16	5.831	0.070	96
RHR system	9	0.627	0.091	17
Volume Control System	14	8.345	0.381	85
FSD Decon area (primary system and auxiliary systems)	76	3.677	0.121	60.5

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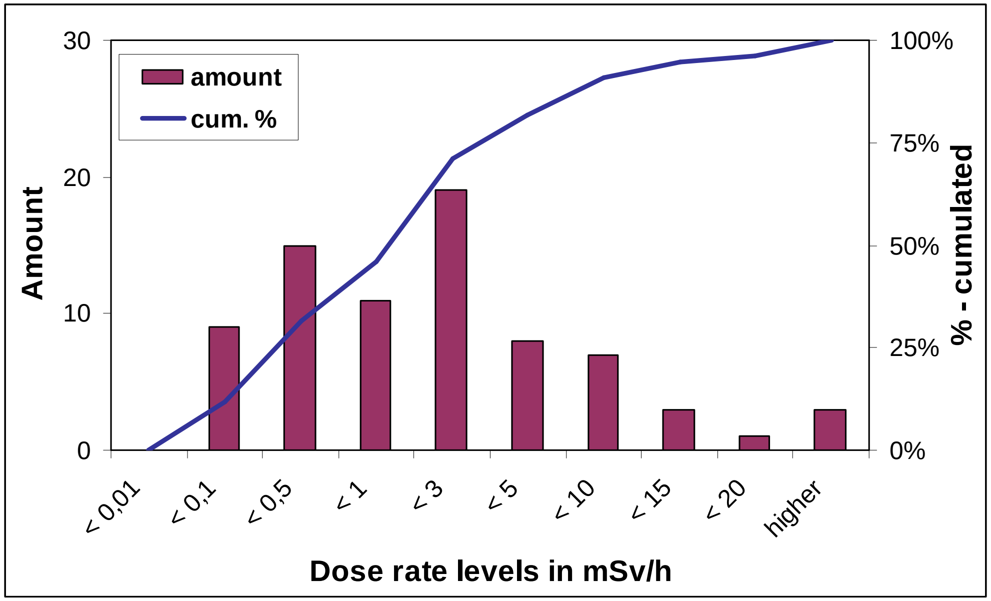
FSD Grafenrheinfeld

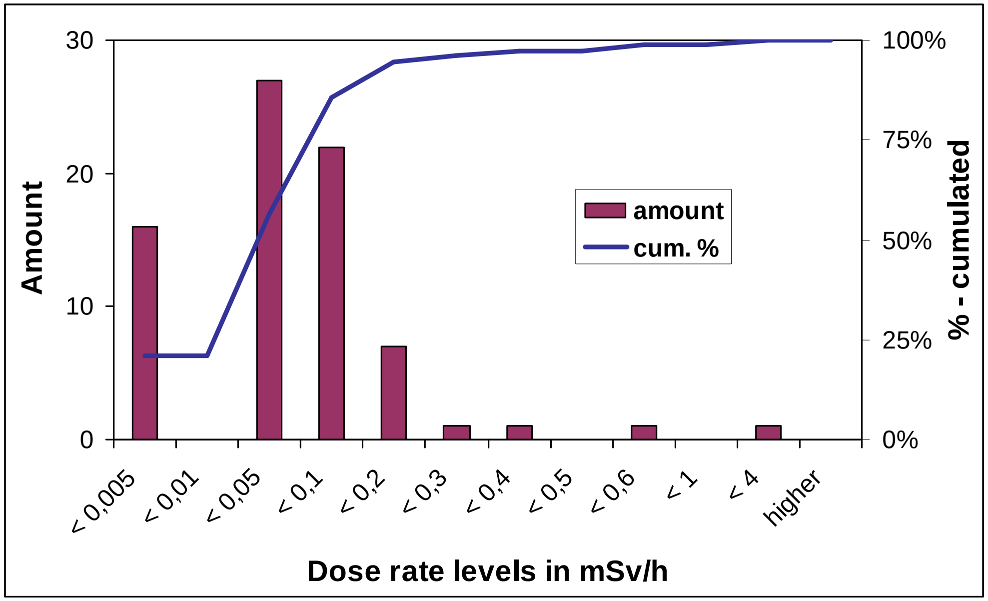
Does Rate Reduction – Distribution in Decon Area

- Dose Rate Level Distribution in Decon Area
  - 76 contractual Measuring Points (MP) with full flow during decontamination
  - > 86% MP lay below 100 µSv/h after FSD
  - **~ 60% MP lay below 50 µSv/h after FSD**
- one MP with dose rates > 3.9 mSv/h after FSD at reg. HX of VCS)

Before FSD

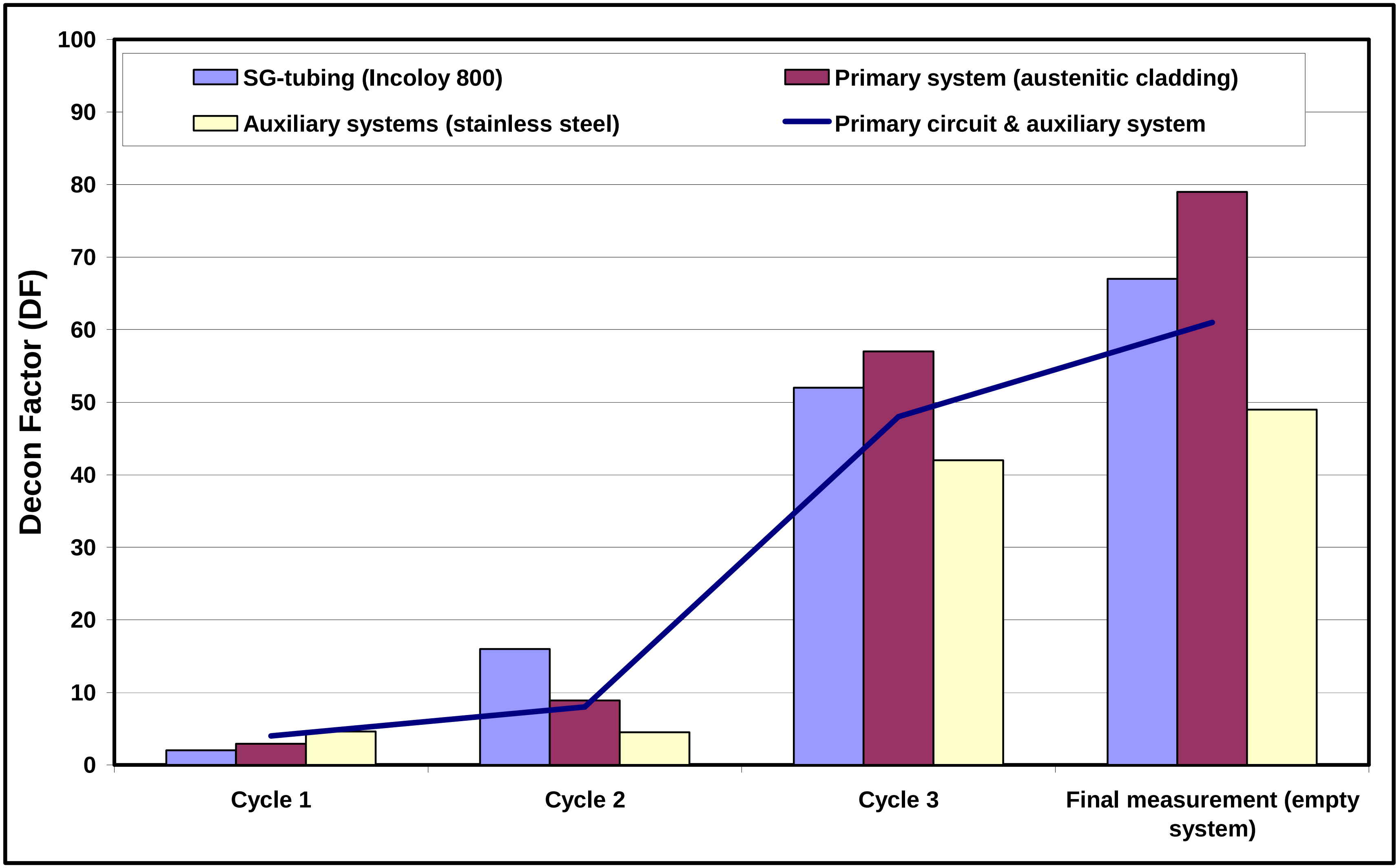


Final Measurement after FSD



FSD Grafenrheinfeld
Homogenous Decon Results over Different Material Areas

DF over the different main material sections on similar level



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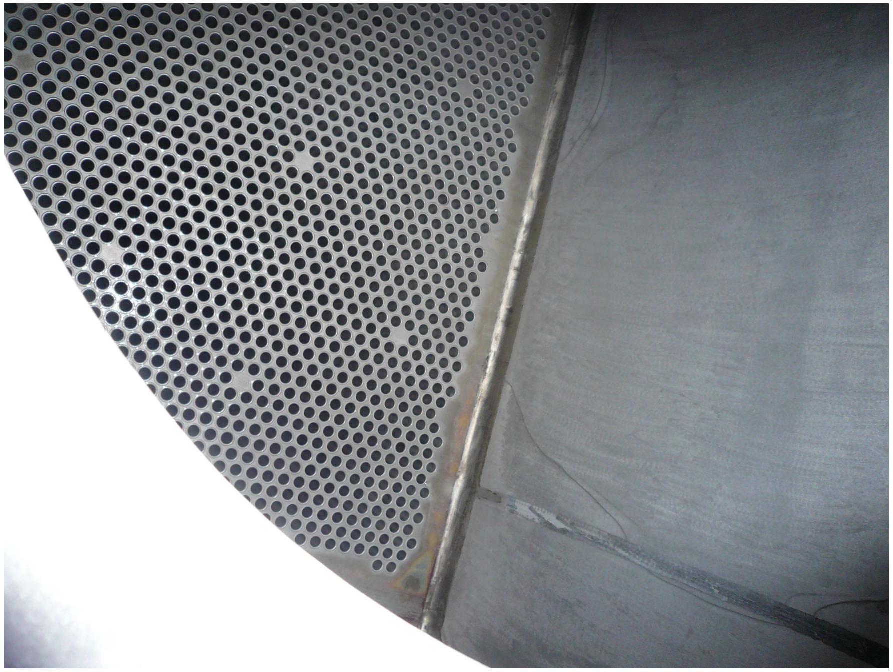
FSD Grafenrheinfeld
Visual Inspection of Steam Generator after FSD

Metallically clean surfaces

AREVA Water Chemistry Concept for Reduction of Recontamination after FSD

- Passivation treatment of the reactor system in plant operation condition "subcritical hot"
- Time duration: 120 hours
- pH value as high as possible for the specified boron and Li concentrations.
- Areva Li limit for the fuel: 10 ppm Li (no temperature gradients and no heat flux in the core during passivation treatment)
- Zinc concentration ≥ 5 ppb
- H_2 concentration at or above the lower limit of the control band specified for power operation
- Start of coolant hydrogenation and Zn and Li additions during heat-up: target is to reach or exceed the recommended values at 260℃
- Other recommendations
  - Use new ion exchange resins
  - High purification flow rate during heat-up and HFT
  - Operate plant during the first three months at constant load (base load operation)

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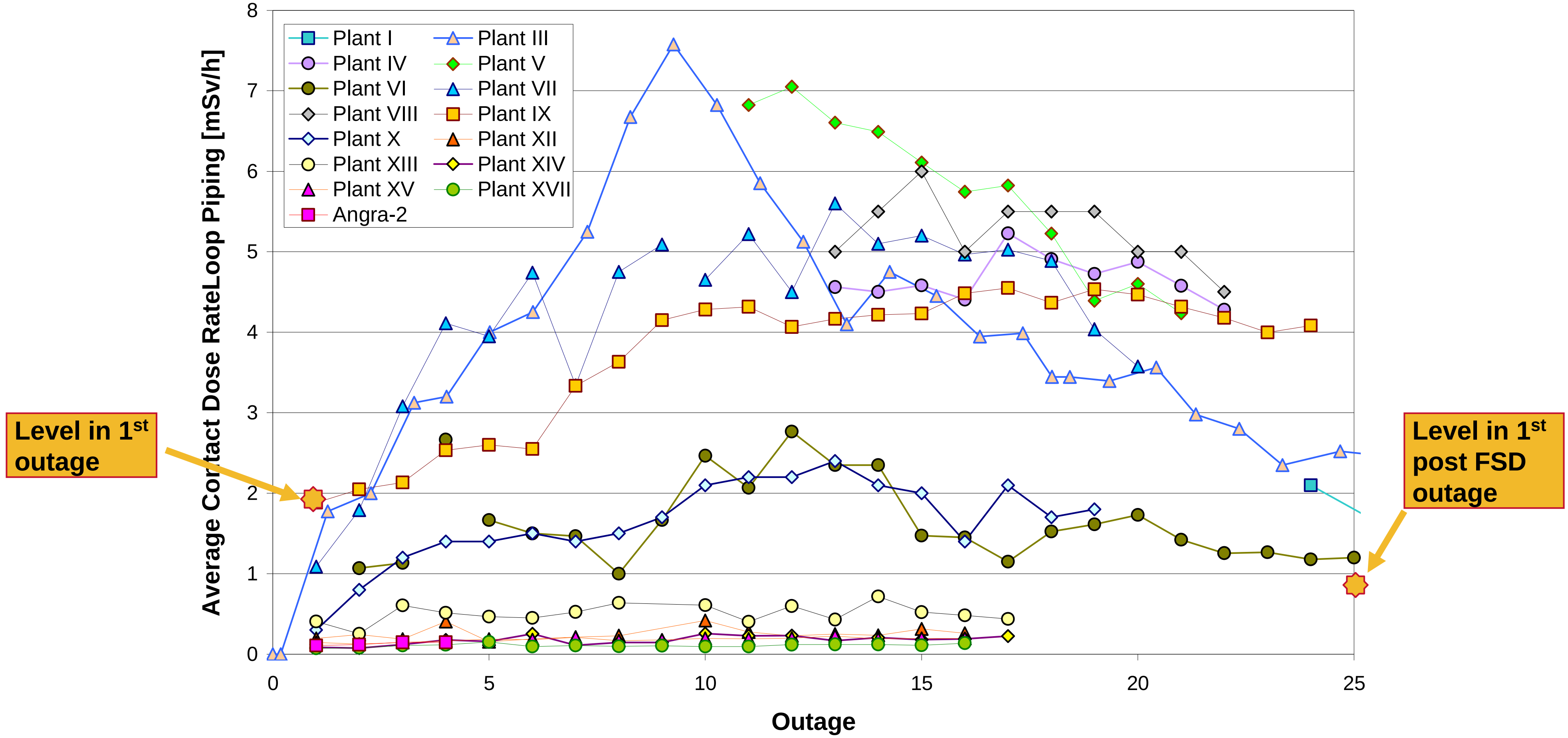
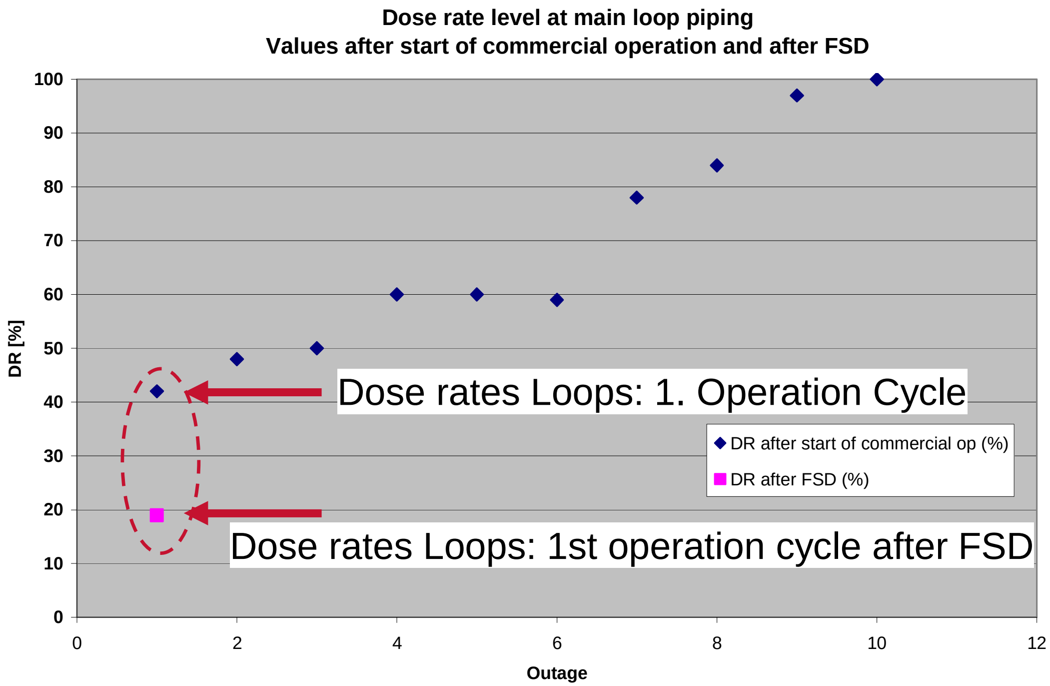
Passivation Treatment at Grafenrheinfeld after FSD

- **Deoxygenation during heat-up:**
  Criterion as specified for the plant, i.e. $O_2 < 0.1$ ppm at 170℃.
- **Hydrogenation start after disconnection of RHR (170℃);**
  target: $H_2 > 2$ ppm before exceeding T = 260℃.
- **Li injection start also at 170℃; target for HFT : L i = 6.3 ± 0.3 ppm.**
- **pH(300℃) ~ 7.1 (B > 2200 ppm)**
- **Zinc injection start also during heatup; concentration 5 - 15 ppb.**
- **Time duration of the passivation treatment:**
  planned 120 hours; conducted 200 hours
- **Base load operation of the plant during the first three months of the cycle**

NPP Grafenrheinfeld
Loop dose rate in 1st post FSD outage

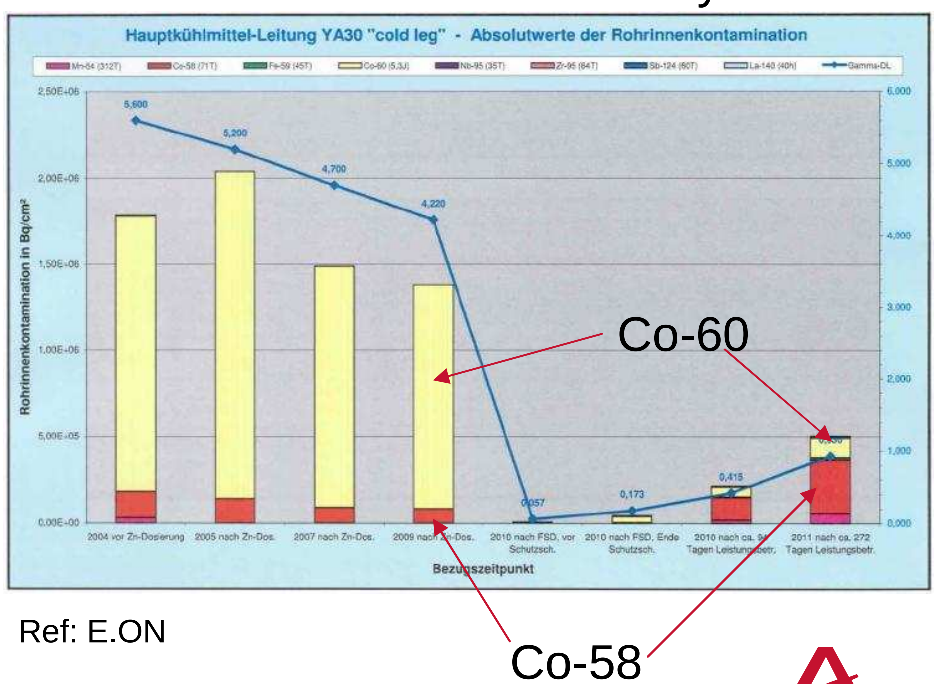


FSD Grafenrheinfeld
Recontamination on Low level



- ► recontamination on expected level
- ► Dose increase after 1st cycle after FSD much lower compared to 1st operation cycle after commissioning
- ► Co-58 as main nuclide will support further dose reductions

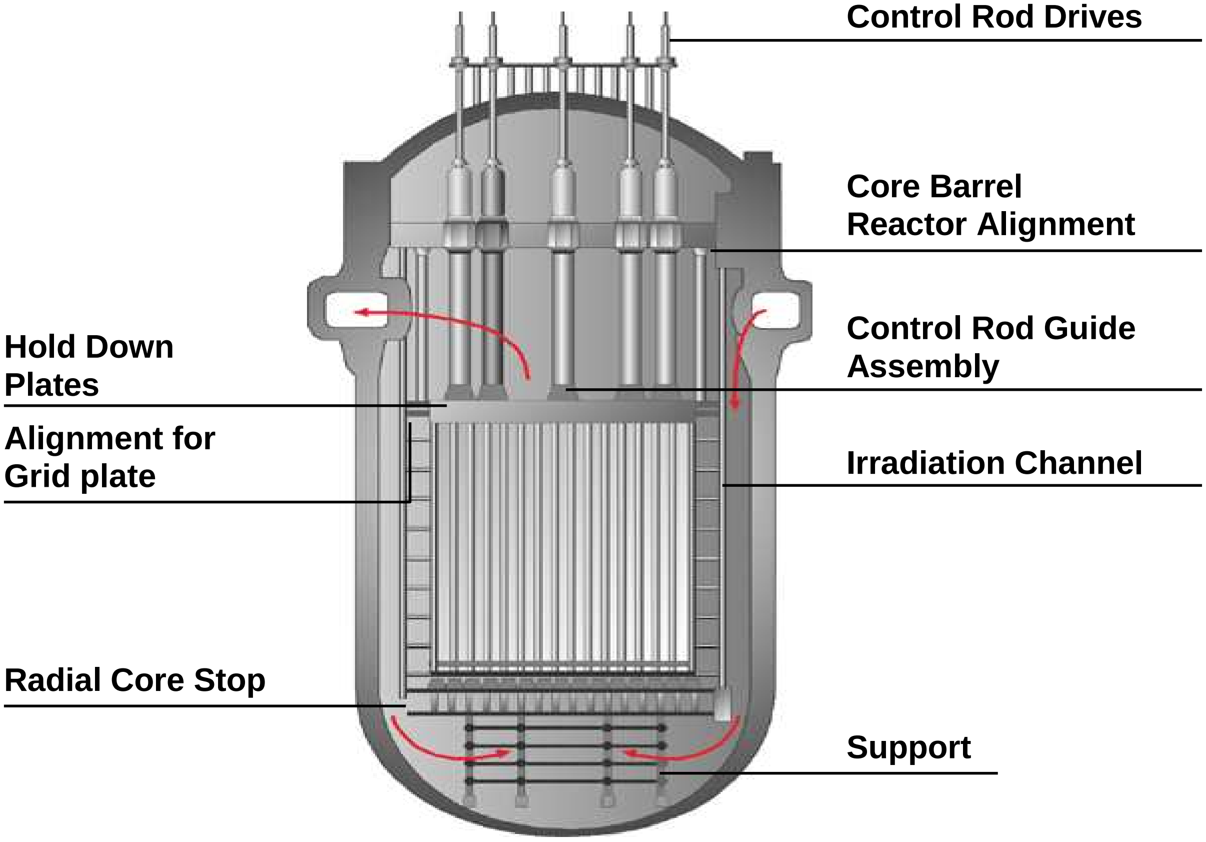
Gamma-scan resulty



Ref: E.ON

Stellite Inventory of Siemens KWU 4-loop Plant Generations

Areas with Co-Base Alloys



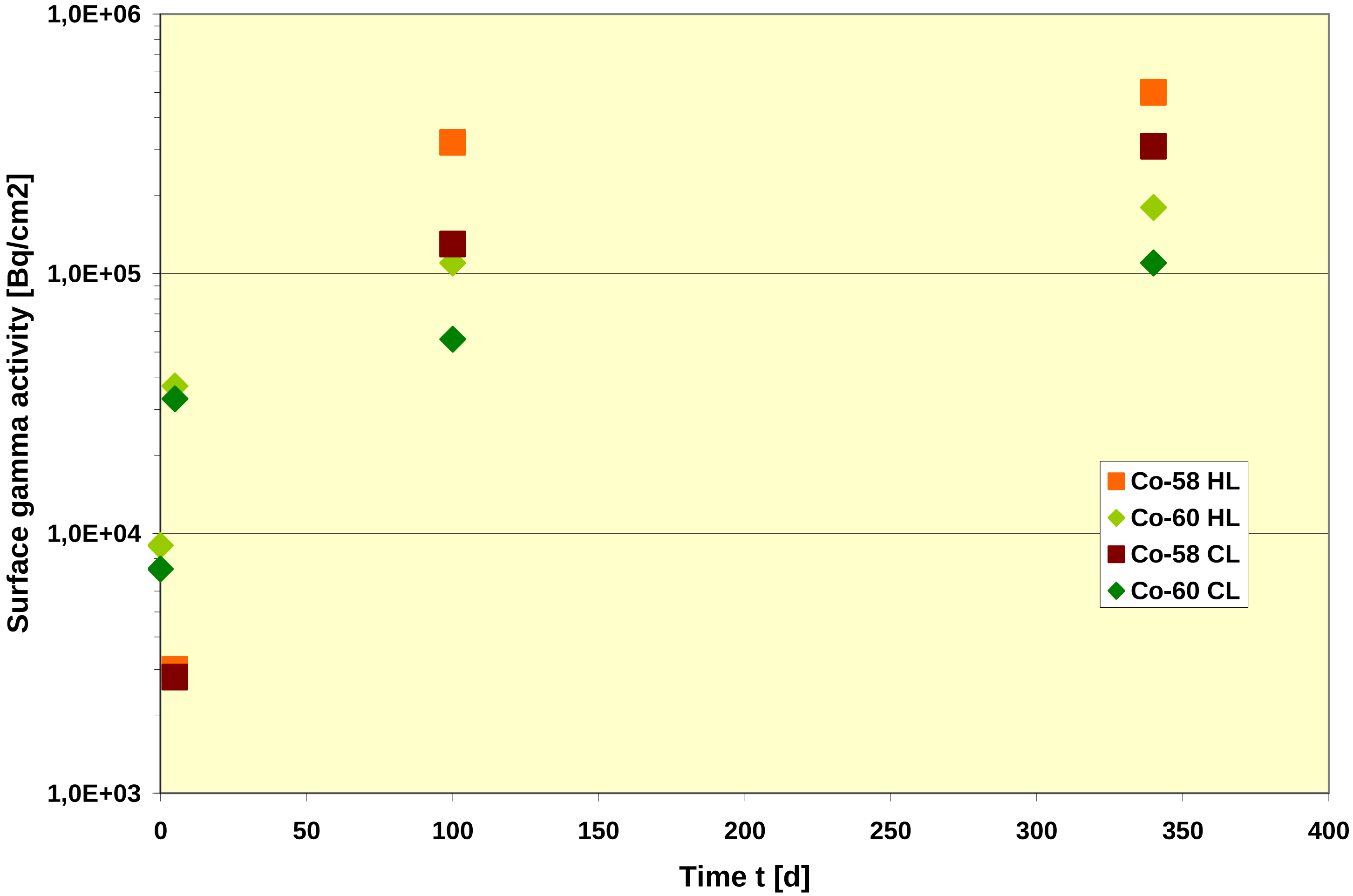
Example: RPV Internals

	Former	Now
Entire Hard-faced Area	Co-base Alloy	Co-base Alloy
Control Rod Drives	1.46 m²	1.46 m²
Core Area	1.59 m²	0.03 m²

Stellite surface in core area

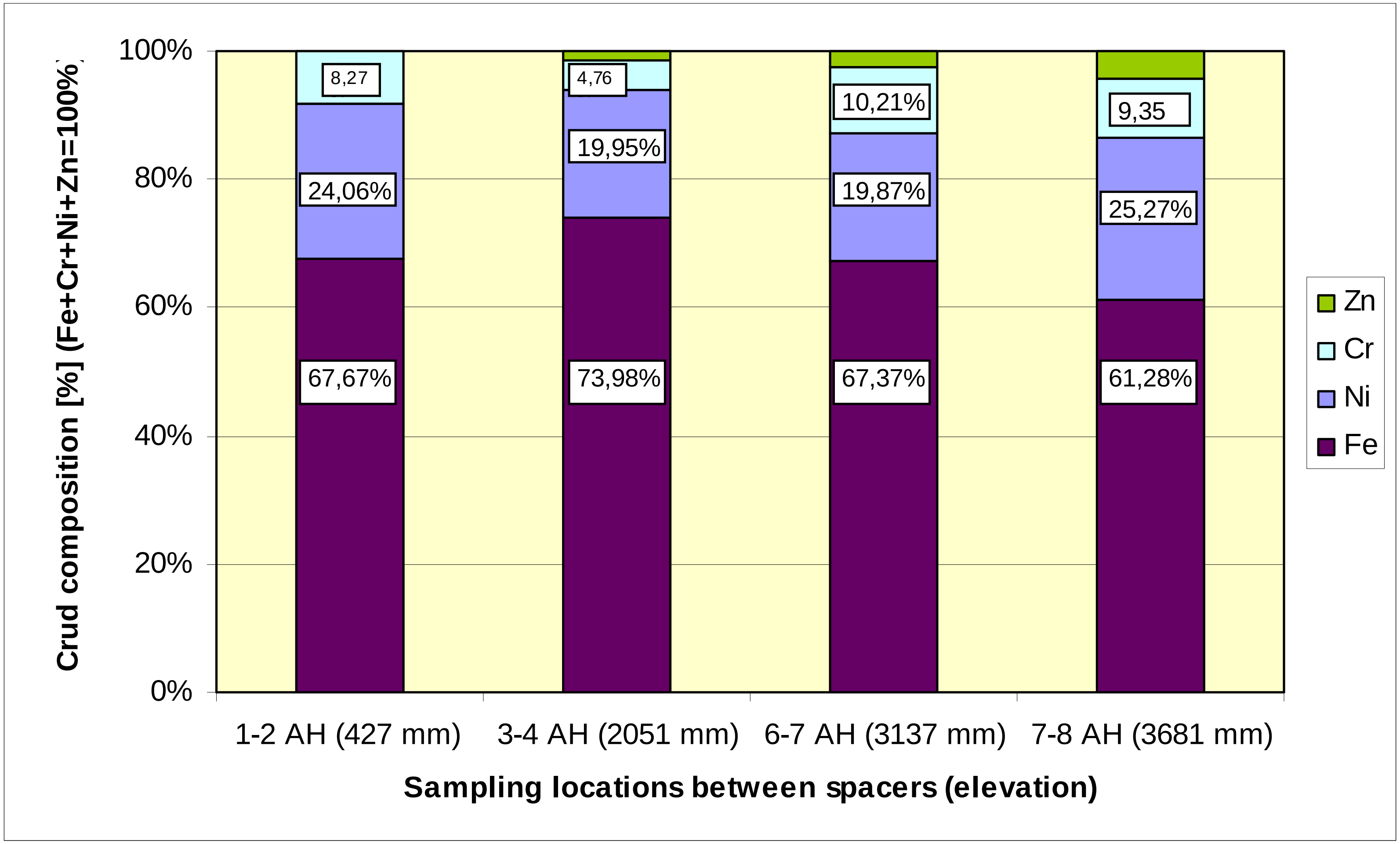
PWR Grafenrheinfeld: All internals activated due to long-term plant operation

Grafenrheinfeld
Surface γ activity values in loop YA 30



Measurements after:
FSD (t = 0), passivation treatment (t = 5 d), HSD (t =100 d) and in post FSD outage (t = 340 d)

Grafenrheinfeld
Crud Composition as a Function of the Elevation



FSD Grafenrheinfeld
Summary

- Good cooperation between E.ON and AREVA during planning and performance of FSD is key for success of such complex project
- Activity release: 2 E 14 Bq
- Achieved of DF 60.5 (average on 76 MP) corresponds with > 98% removed activity from the primary system and auxiliary systems
- 19.4 m³ resin waste (18.6 m³ planned)
  - Resin waste processing started within FSD performance
  - 7 m³ AIX could be disposed in HICs (Mosaik container) with low shielding
- Special flushing program modified successfully during FSD performance in close cooperation of E.ON & AREVA
- Inspection program performed to ensure functionality of components
- Final clean-up of coolant after FSD performed to meet site requirements for start up
- Protective layer build up performed without problems
- CRE savings:
  - In outage direct after FSD: approx. 3400 mSv
  - In outage after 1st cycle: approx. 1500 mSv
- Recontamination on low level
- Close partnership between E.ON and AREVA for analyzing recontamination effects and also in application of post-FSD measures to support low recontamination

Summary
AREVA NP Concept for Sustainable Dose Reduction

- **Concept is basing on proven technologies**
  - **HP/CORD UV**
    - References
    - Material compatibility
    - Low waste volumes
  - **AMDA**
    - Proven and reliable technology since more than 30 years
  - **FSD**
    - Experiences and development for FSDs for decommissioning
    - References for FSDs in operating NPPs without negative experiences during the following cycles (e.g. OKG 1 and Loviisa 2 now > 10 years in operation after FSD)
    - System integrity and functionality of components after FSD
- **Protective Layer build up**
  - **References of new builds and for SG replacement**
- **Zn-Injection (DZO)**
  - **References**
    - Before first criticality: NPP Angra 2
    - Implementation after severall cycles: worldwide operating NPPs

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