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Decontamination
in preparation for dismantlement

AREVA's chemical decontamination technologies
projects performed and results obtained
in the period 2011-2016

Luis SEMPERE BELDA
AREVA EXPERT
CHEMICAL PROCESS SUPERVISOR
FOR FULL SYSTEM DECONTAMINATIONS

Sarpsborg, February 8th 2017

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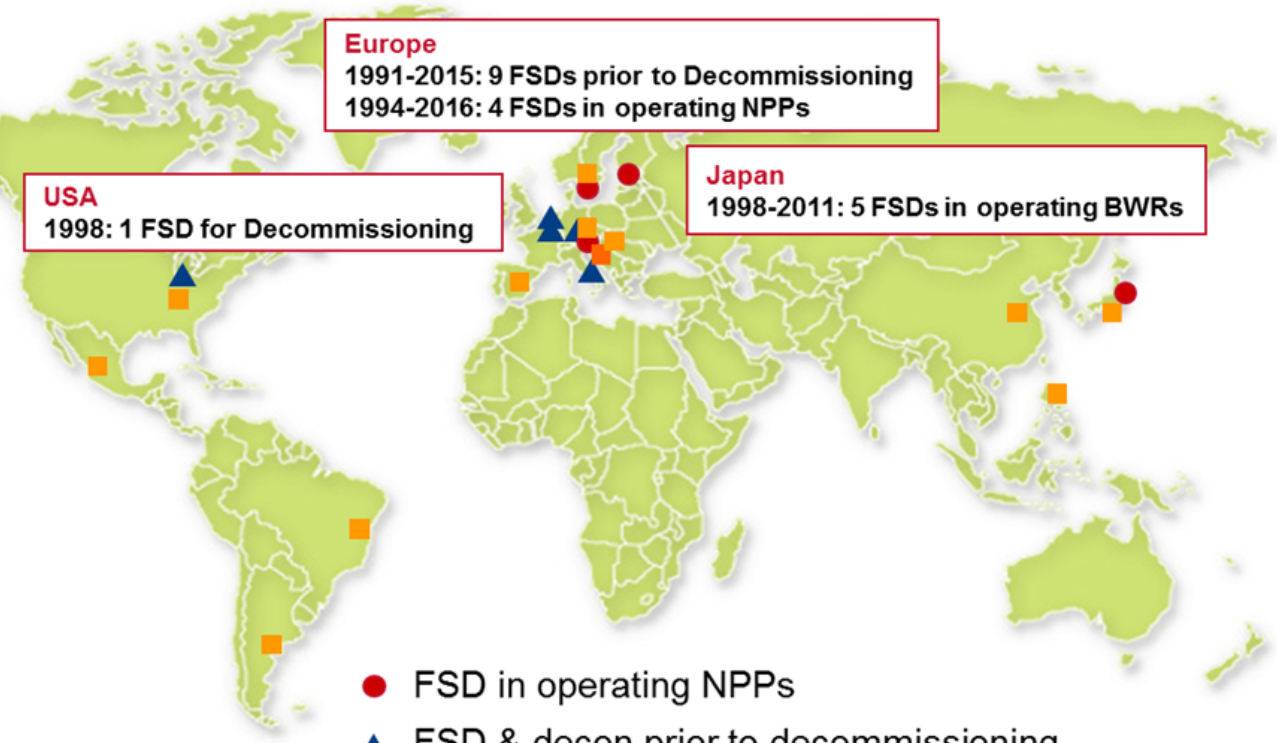
AREVAs Worldwide Experience

in Chemical Decontamination covering all main NPP Designs

NPP / Country	Type / OEM	Year
Decommissioning		
FR 2 / Germany	PWR / AREVA	1986
Gundremmingen A / Germany	BWR / GE	1989
BR 3 Mol / Belgium	PWR / Westinghouse	1991
VAK Kahl / Germany	BWR / GE / AEG	1992 / 93
Rheinsberg / Germany	PWR / WER	1994
MZFR / Germany	PHWR / AREVA	1995
Würgassen / Germany	BWR / GE	1997 / 98
Connecticut Yankee / USA	PWR / Westinghouse	1998
Lingen / Germany	BWR / GE	2001
Caorso / Italy	BWR / GE	2004
Trino / Italy	PWR / Westinghouse	2004
Stade, Germany	PWR / AREVA	2004
Obrigheim, Germany	PWR / AREVA	2007
Barsebäck 1, Sweden	BWR / ABB	2007
Barsebäck 2, Sweden	BWR / ABB	2008
Chooz A, France	PWR / AREVA	2011/2012
Unterweser, Germany	PWR / AREVA	2012
Neckarwestheim-1, Germany	PWR / AREVA	2013
Isar 1, Germany	BWR / AREVA	2015
Grafenrheinfeld, Germany	PWR / AREVA	2016
Return to Service / Stand Still Operation		
Oskarshamn 1 / Sweden	BWR / ABB	1994
Loviisa 2 / Finnland	WER / AEE	1994
Fukushima Daiichi / Japan Units 1 to 5	BWR / GE, Toshiba, Hitachi	1997- 2011
Grafenrheinfeld / Germany	PWR / AREVA	2010
Krümmel, Germany	BWR / AREVA	2016



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The Chooz A dismantlement 2011/2012: Pioneering D&D in France

CHOOZ-A 2011/12	
OEM	WESTINGHOUSE
TYPE	PWR - 4 LOOP
OPERATED BY	EDF
CAPACITY	305 MWe
OPERATION	1967 - 1993
D&D STRATEGY	SAFSTOR - COMPONENTS

DECON PROJECT HIGHLIGHTS:

- DECONTAMINATION AFTER SAFSTOR
- PRIMARY COOLANT CIRCUIT NON-OPERATIONAL
- COMPONENT-BY-COMPONENT TREATMENT REQUIRED
- OXIDE REMOVAL AND BASE METAL REMOVAL PERFORMED
- LESSONS LEARNED:
  - CHEMICAL PROCESS CONTROL
  - ION EXCHANGE RESIN MANAGEMENT
  - OPTIMIZATIONS IN DECON EQUIPMENT & TECHNOLOGY

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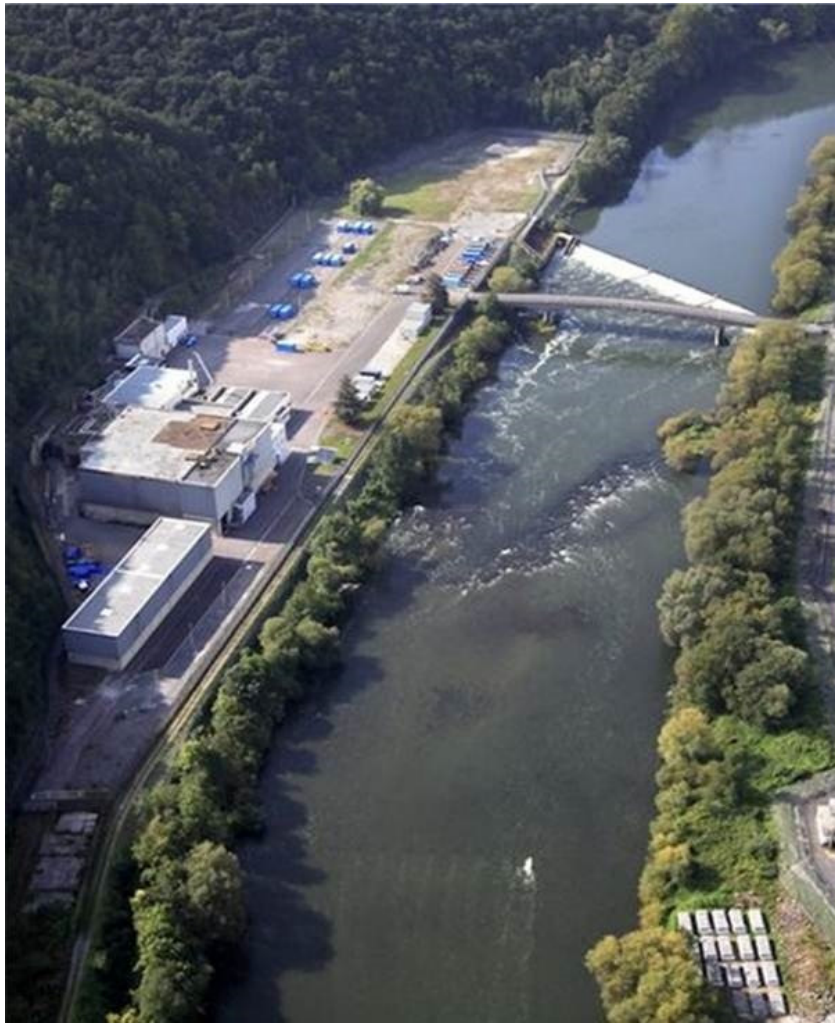

Picture: EdF

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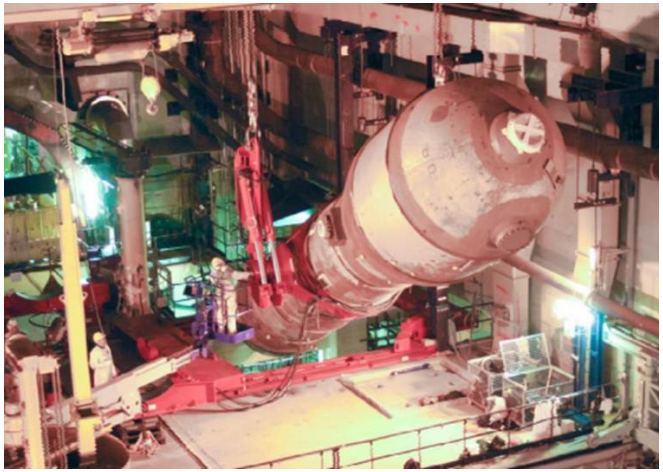
The Chooz A Dismantlement 2011/2012:
Non operational primary circuit



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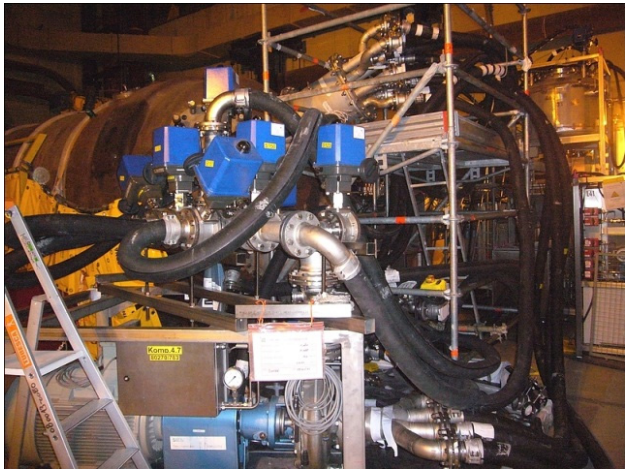
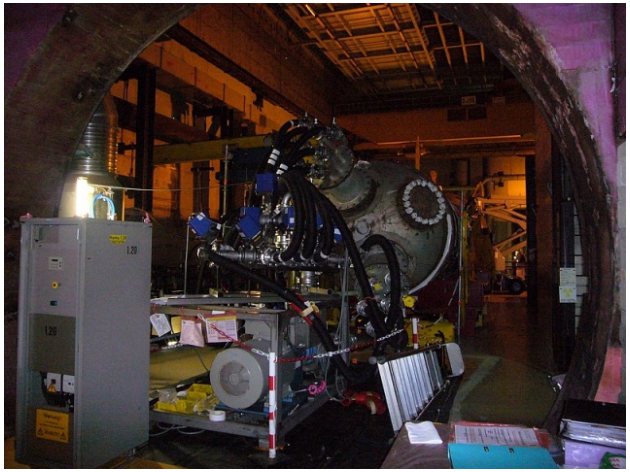


Picture: AREVA



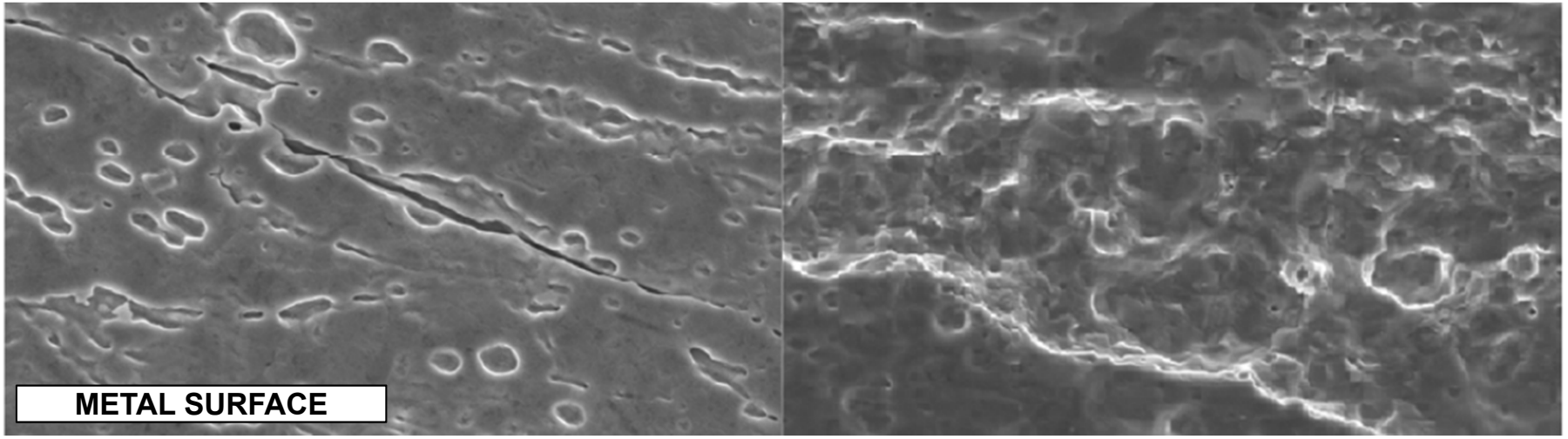
Picture: AREVA

- **RPV was dismantled "as is" without decontamination**
- **Steam Generators were extracted and decontaminated horizontally**
- **Pressurizer was decontaminated in vertical position**
- **Loop piping was decontaminated in pairs (loop 1&2 and loop 3&4 together)**
- **AREVA's AMDA was used as external decontamination equipment**
- **Oxide removal performed with AREVA's decon process HP CORD UV**
- **Base metal removal performed with AREVA's decon process CORD D**

CORD D for controlled base metal removal
an inherently safe process using harmless* chemicals

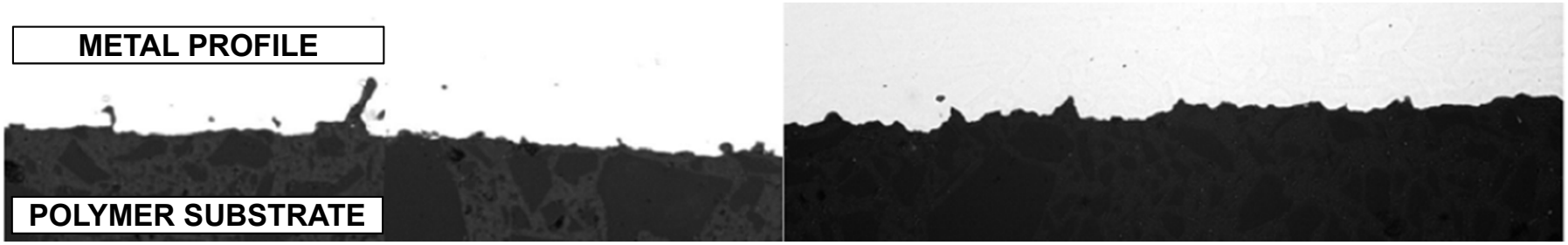
- Metastable process conditions: UV-forced reaction working only under very specific conditions ceases automatically in case of equipment failure
- * Employs the organic oxalic acid (HOOC-COOH) as process chemical, much safer for handling than hydrofluoric acid or other alternative mineral acids commonly used for base metal removal
- Base metal removal depth controllable to sub-micrometer precision
- Dynamic control based on dose rate or activity measurements possible
- Oxalic acid is decomposed to CO2 at the end of the reaction, does not require complicated, expensive disposal as radwaste

CORD D for base metal removal
for when surface imperfections make decon difficult



Metal surface presenting imperfections were activity can accumulate, making decontamination difficult

Base metal removal with CORD D (here 6 µm) makes the activity accessible



The Chooz A Dismantlement 2011/2012:
Mission accomplished - Components leave Controlled Area as VLLW

- **Oxide layer and base metal removed from all the large components**
- **Steam Generators left the Chooz site reclassified as VLLW to French storage facility (ANDRA)**
- **First components ever to leave controlled area in France**

Steam generator's radiological characteristics

BEFORE	AFTER
40 000 Bq/cm²	40 Bq/cm² (CORD)
40 000 Bq/cm²	2 000 Bq/cm² (other treatment for plugged tubes)
700 µSv/h	1 µSv/h
450 GBq Co60	0.65 GBq Co60

Pictures: EdF

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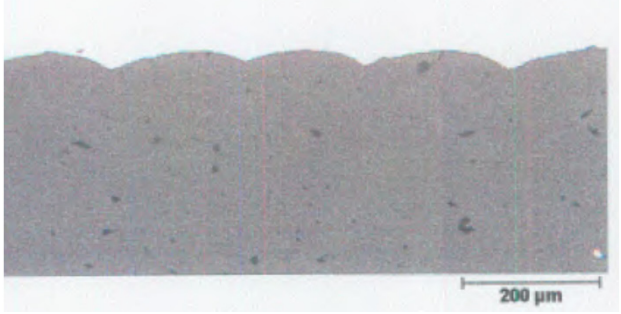
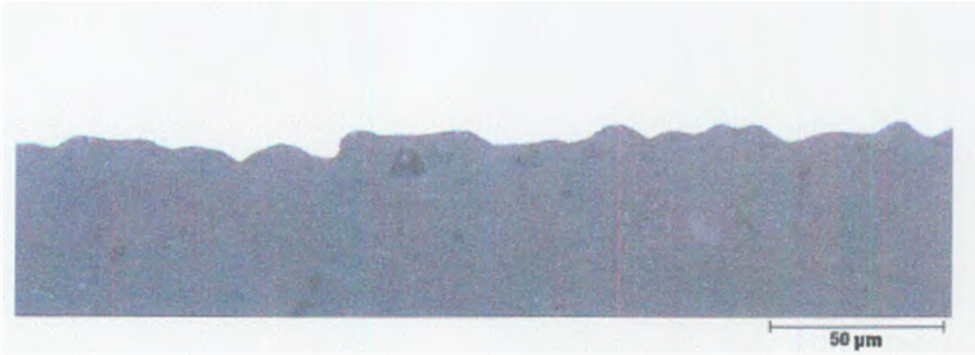
HP CORD UV - developed for outage service
very effective as well in preparation for dismantlement

- **HP CORD UV *without base metal removal* chosen for FSDs in preparation for dismantlement in Germany**
- **Innocuousness to material under HP CORD UV application conditions confirmed by recurrent examinations on real plant material - Extensive database**
- **Below: Exemplary metallographic analysis of real nuclear power plant tubing, cut out after 24 years in operation**

REAL TUBING MATERIAL, GERMAN NUCLEAR POWER PLANT - (24 YEARS IN OPERATION)
SIX (6) DECONTAMINATION CAMPAIGNS WITH CORD – DOSE REDUCTION DURING OUTAGE EXPOSED TO NINETEEN (19) CORD CYCLES UNDER ACTUAL APPLICATION CONDITIONS
EXAMINATION RESULTS:
• GENERAL ROUGHNESS OF PIPE SURFACE BELOW 10 µm • MATERIAL STILL WITHIN TECHNICAL SPECIFICATIONS FOR CONSTRUCTION • CLEARLY DEFINED MACHINING MARKS FROM TIME OF CONSTRUCTION IN END OF TUBE PROVE ABSENCE OF SIGNIFICANT MATERIAL LOSS

CLEARLY DEFINED MACHINING MARKS FROM THE TIME OF CONSTRUCTION EVEN AFTER 24 YEARS IN OPERATION AND 6 DECONTAMINATION CAMPAIGNS WITH A TOTAL OF 19 CORD CYCLES (=no material loss)





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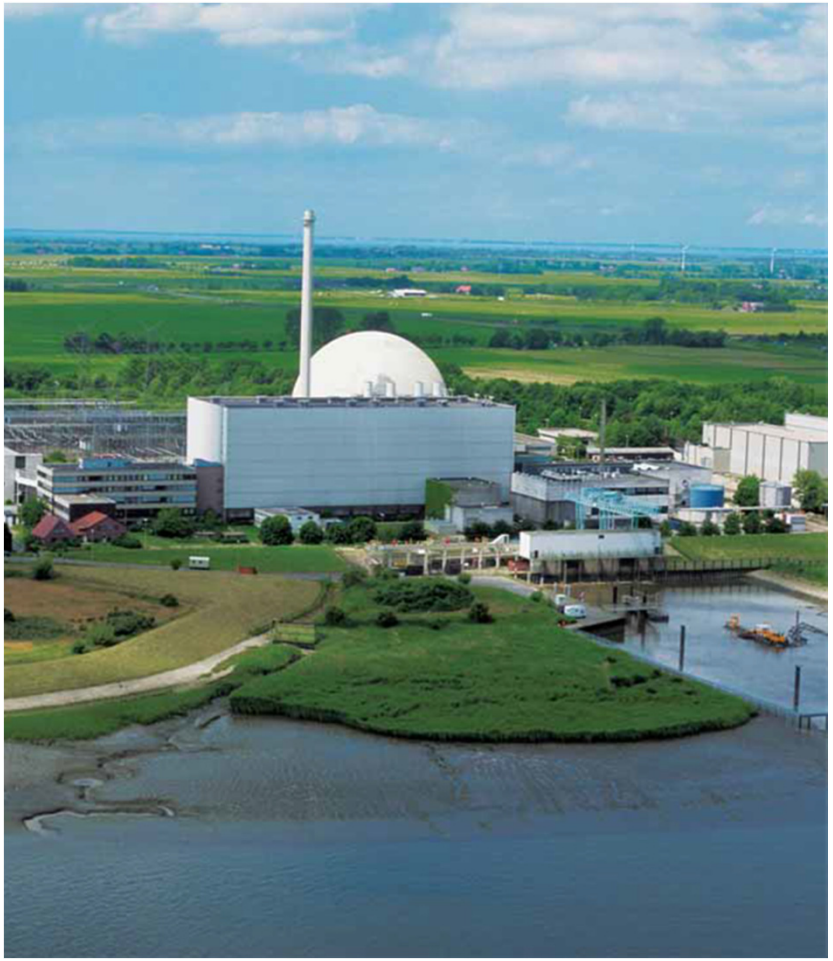
Full System Decontamination in 2012: PWR KKU – Northern Germany

UNTERWESER (KKU) 2012	
OEM	SIEMENS KWU (AREVA)
TYPE	PWR - 4 LOOP
OPERATED BY	EON (PREUSSEN ELEKTRA)
CAPACITY	1410 MWe
OPERATION	1979 - 2011
D&D STRATEGY	EARLY - FSD



Picture: EON

DECON PROJECT HIGHLIGHTS:

- FIRST FSD AFTER GERMAN PHASE-OUT
- IMPLEMENTED LESSONS LEARNED -INC. CHOOZ- AND NEW EQUIP. & TECHNOLOGIES
- EVERYTHING ACCORDING TO PLAN
  - COSTS
  - ESTIMATED WASTE
  - RESULTS
  - SCHEDULE
- AVERAGE DF> 90 - TOTAL DOSE 75 mSv
- THOROUGH, METICULOUS INSPECTION OF PRIMARY CIRCUIT AFTER COMPLETION SUPERVISED BY INDEPENDENT TECHNICAL CERTIFICATION AGENCY TÜV - RESULT:

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"FROM A TECHNICAL POINT OF VIEW, THE PLANT COULD RETURN TO OPERATION" ✓

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Full System Decontamination in 2013: PWR GKN1 – Southern Germany

NECKARWESTHEIM-1 (GKN1) 2013	
OEM	SIEMENS KWU (AREVA)
TYPE	PWR - 3 LOOP
OPERATED BY	EnBW
CAPACITY	860 MWe
OPERATION	1976 - 2011
D&D STRATEGY	EARLY - FSD

Picture: EnBW

DECON PROJECT HIGHLIGHTS:

- MAINTAINED BEST PRACTICES FROM KKU
- INTRODUCED ADDITIONAL IMPROVEMENTS ENABLING:
  - REDUCTION OF APPLICATION TIME (25d vs KKU's 35d)
  - 20% SAVING OF IX-WASTE VOLUME vs PLAN
- AVERAGE DF> 80 - TOTAL DOSE 61 mSv
- TECHNICAL POSSIBILITY TO RETURN TO SERVICE INDEPENDENTLY CERTIFIED ✓

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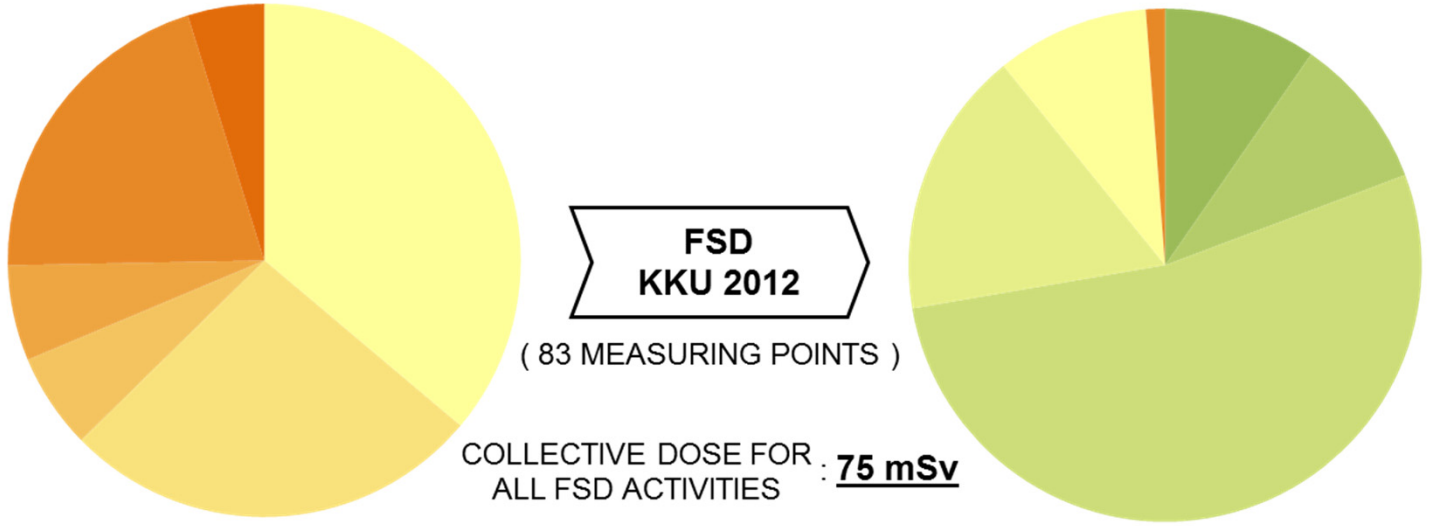
Full System Decontamination KKU & GKN1
distribution of contact dose rates before / after FSD

KKU 2012	NUMBER OF MEASURING POINTS IN THE SYSTEM WITH DOSE RATE / (mSv/h)									
	<0,005	< 0,01	< 0,05	< 0,1	< 0,5	< 1	< 2	< 5	< 10	< 20
before FSD	0	0	0	0	30	22	5	5	17	4
after FSD	8	8	44	14	8	0	0	0	1	0

GKN1 2013	NUMBER OF MEASURING POINTS IN THE SYSTEM WITH DOSE RATE / (mSv/h)									
	<0,005	< 0,01	< 0,05	< 0,1	< 0,5	< 1	< 2	< 5	< 10	< 20
before FSD	0	0	4	4	25	20	7	5	1	0
after FSD	13	7	35	4	4	2	1	0	0	0

Full System Decontamination KKU & GKN1
distribution of contact dose rates before / after FSD

mSv/h
< 20
< 10
< 5
< 2
< 1
< 0.5
< 0.1
< 0.05
< 0.01
< 0.005



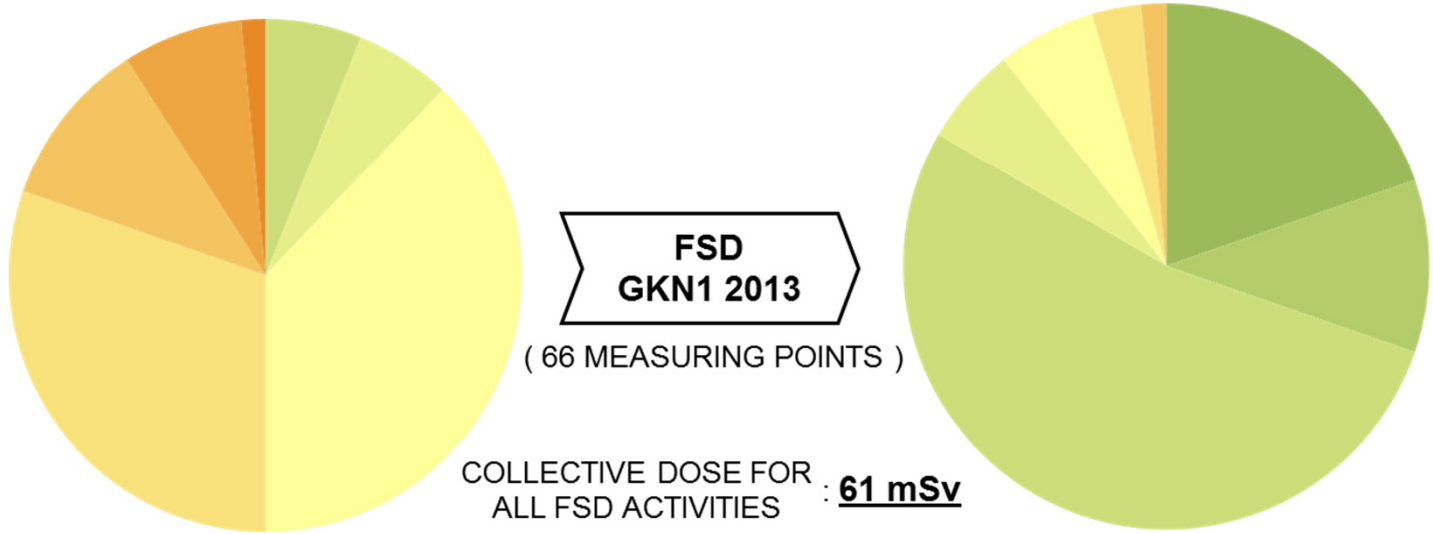
FSD KKU 2012

(83 MEASURING POINTS)

COLLECTIVE DOSE FOR ALL FSD ACTIVITIES : **75 mSv**

BEFORE FSD

AFTER FSD



FSD GKN1 2013

(66 MEASURING POINTS)

COLLECTIVE DOSE FOR ALL FSD ACTIVITIES : **61 mSv**

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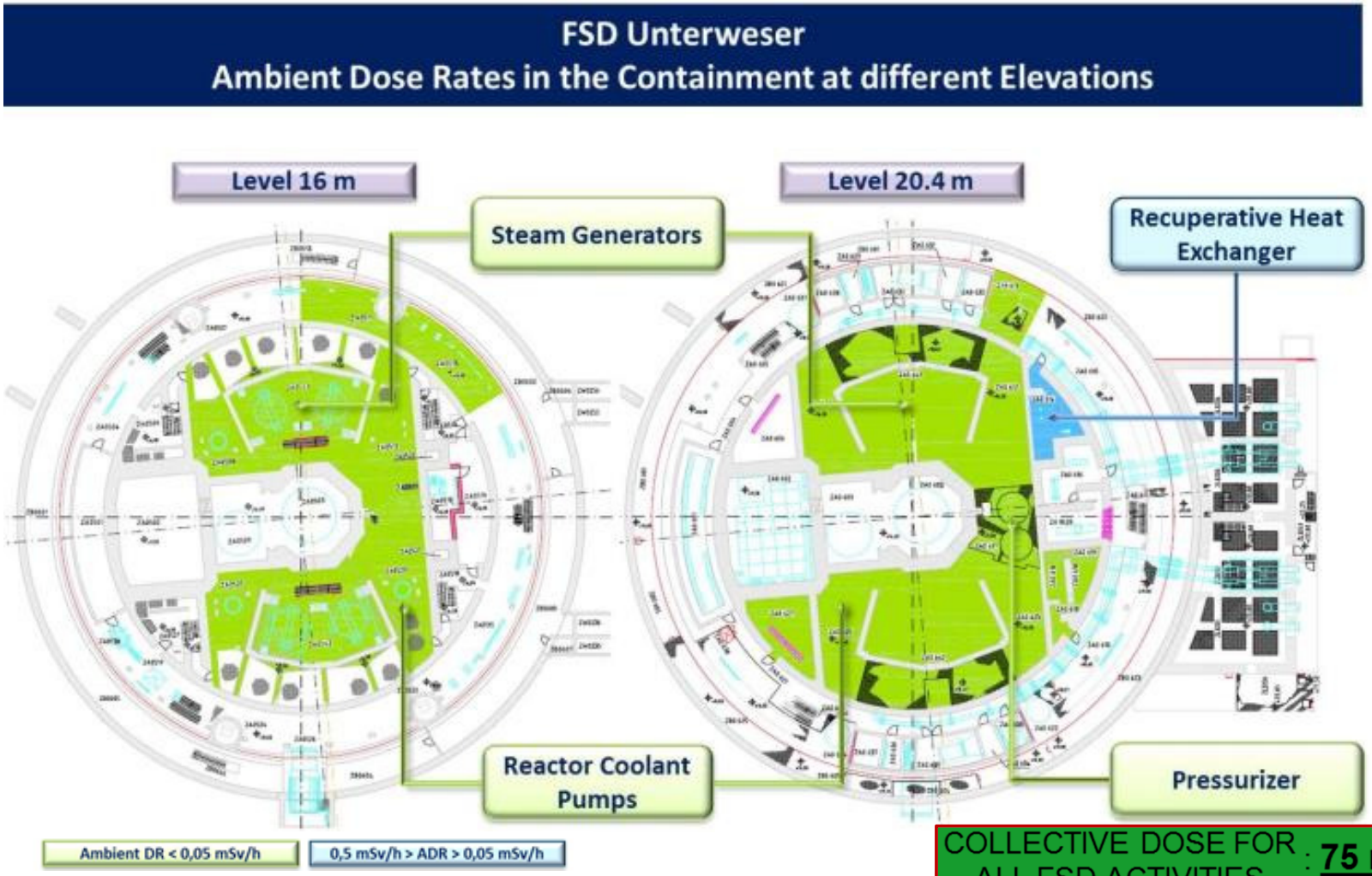
Full System Decontamination KKU & GKN1: Ambient dose rate reduction up to factor 100



COLLECTIVE DOSE FOR ALL FSD ACTIVITIES : **75 mSv**

Overall collective dose savings for D&D work: 100 Sv (KKU utility estimate)

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INVEST 7.5 REM, SAVE 10 000 REM

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Full System Decontamination in 2015: BWR KKI1 – Southern Germany

ISAR-1 (KKI1) 2015	
OEM	SIEMENS KWU (AREVA)
TYPE	BWR
OPERATED BY	EON (PREUSSEN-ELEKTRA)
CAPACITY	912 MWe
OPERATION	1977 - 2011
D&D STRATEGY	EARLY - FSD

Picture: EON

DECON PROJECT HIGHLIGHTS:

- FIRST BWR FSD AFTER NUCLEAR PHASE-OUT
- MATERIAL MIX: STAINLESS STEEL + CARBON STEEL
- FOCUS ON DECON OF RPV INTERNALS
- HIGH DF ON STEAM DRYER ENABLES DRY-CUTTING TECH INSTEAD OF UNDERWATER
- WASTE REDUCTION TECH INCLUDING QUALIFICATION OF HIGH CAPACITY RESIN
- APPLICATION OF CORD P
- **TECHNICAL POSSIBILITY TO RETURN TO SERVICE INDEPENDENTLY CERTIFIED** ✓

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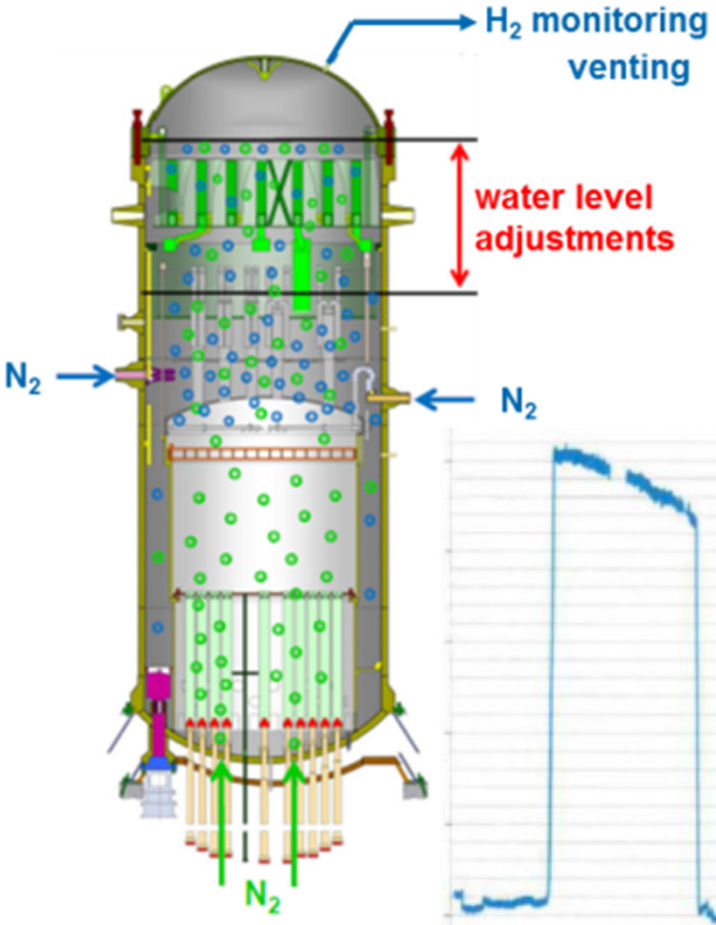
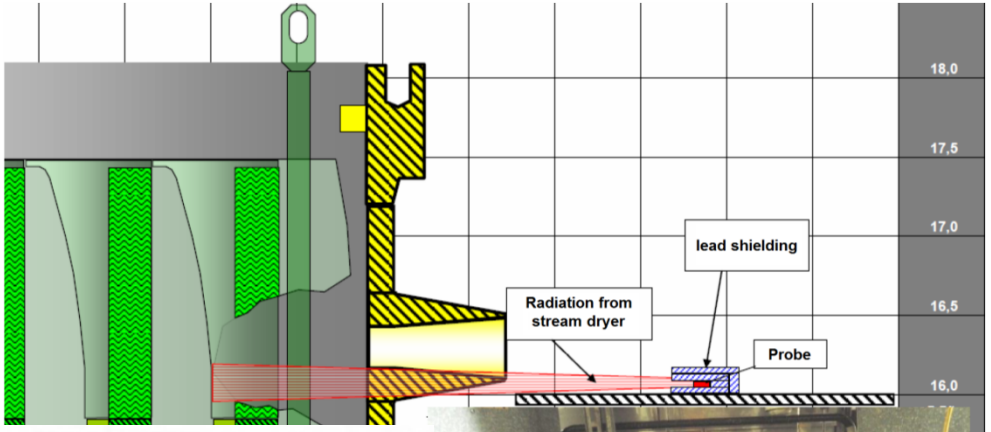
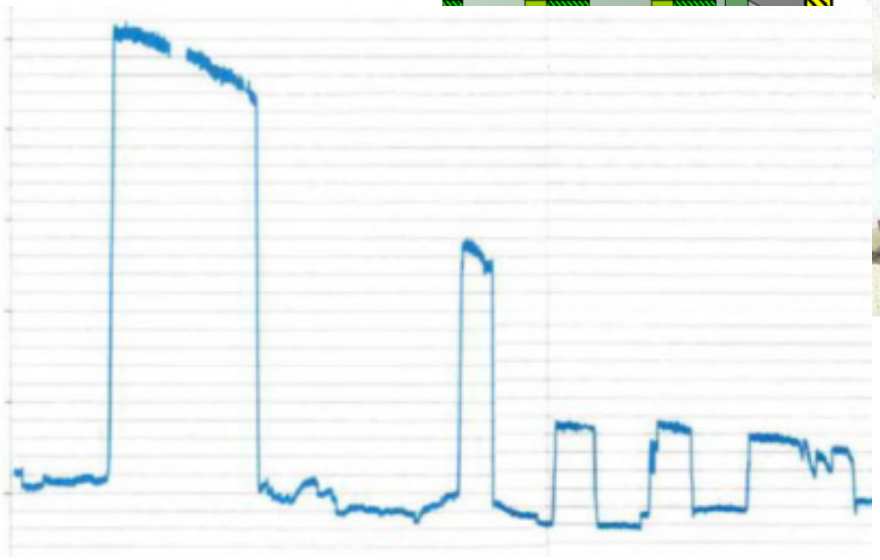
Process engineering for FSD in KKI1 successful by working together







Based on slides by

e·on

The excellent cooperation between teams and fantastic contributions such as these from the operating personnel of these plants made all these projects so successful!

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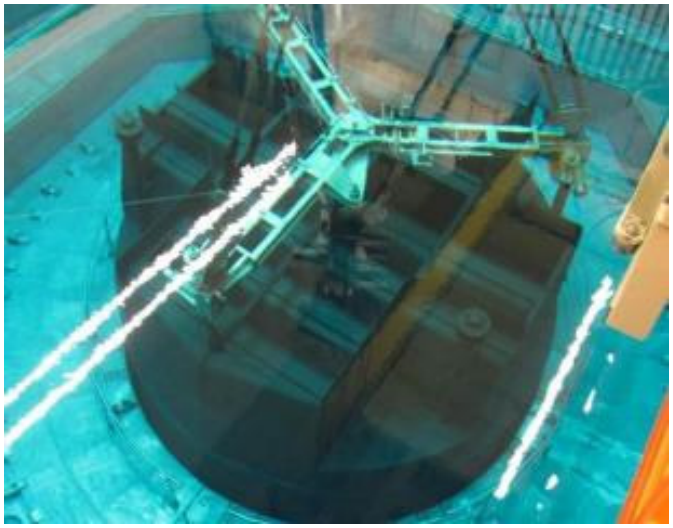
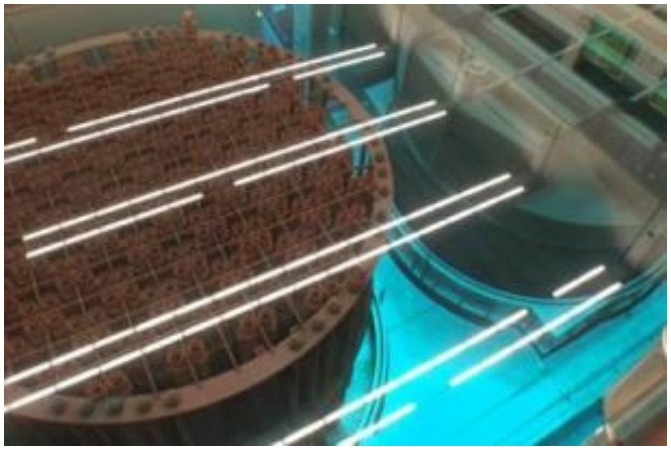
Full System Decontamination KKI 1
BWR KKI 1 – Steam Dryer & Water Separator Results

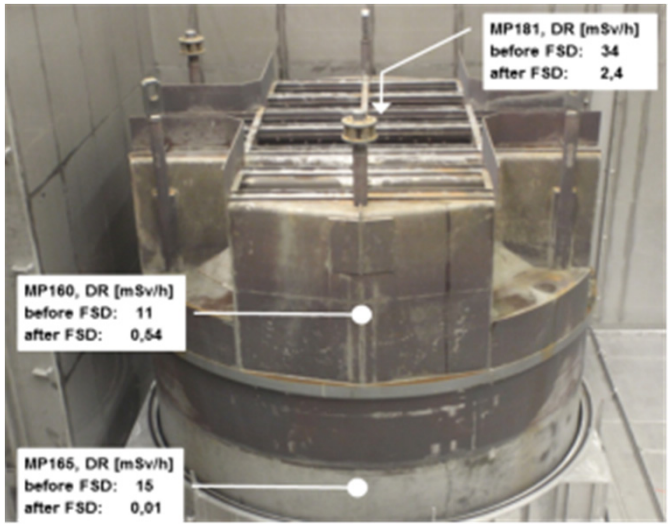
STEAM DRYER BEFORE FSD
IN UNDERWATER STORAGE (2012)





WATER SEPARATOR BEFORE FSD IN
UNDERWATER STORAGE (2012)

STEAM DRYER IN DRY STORAGE
LOCATION AFTER FSD (2015)



WATER SEPARATOR ABOVE
WATER LEVEL AFTER FSD (2015)

Pictures: EON

NO AIRBORNE RELATED ACTIVITY DETECTED

FOLLOW UP OF DRY CUTTING TECHNIQUES FOR STEAM DRYER BY KKI

STEAM DRYER DF = 46

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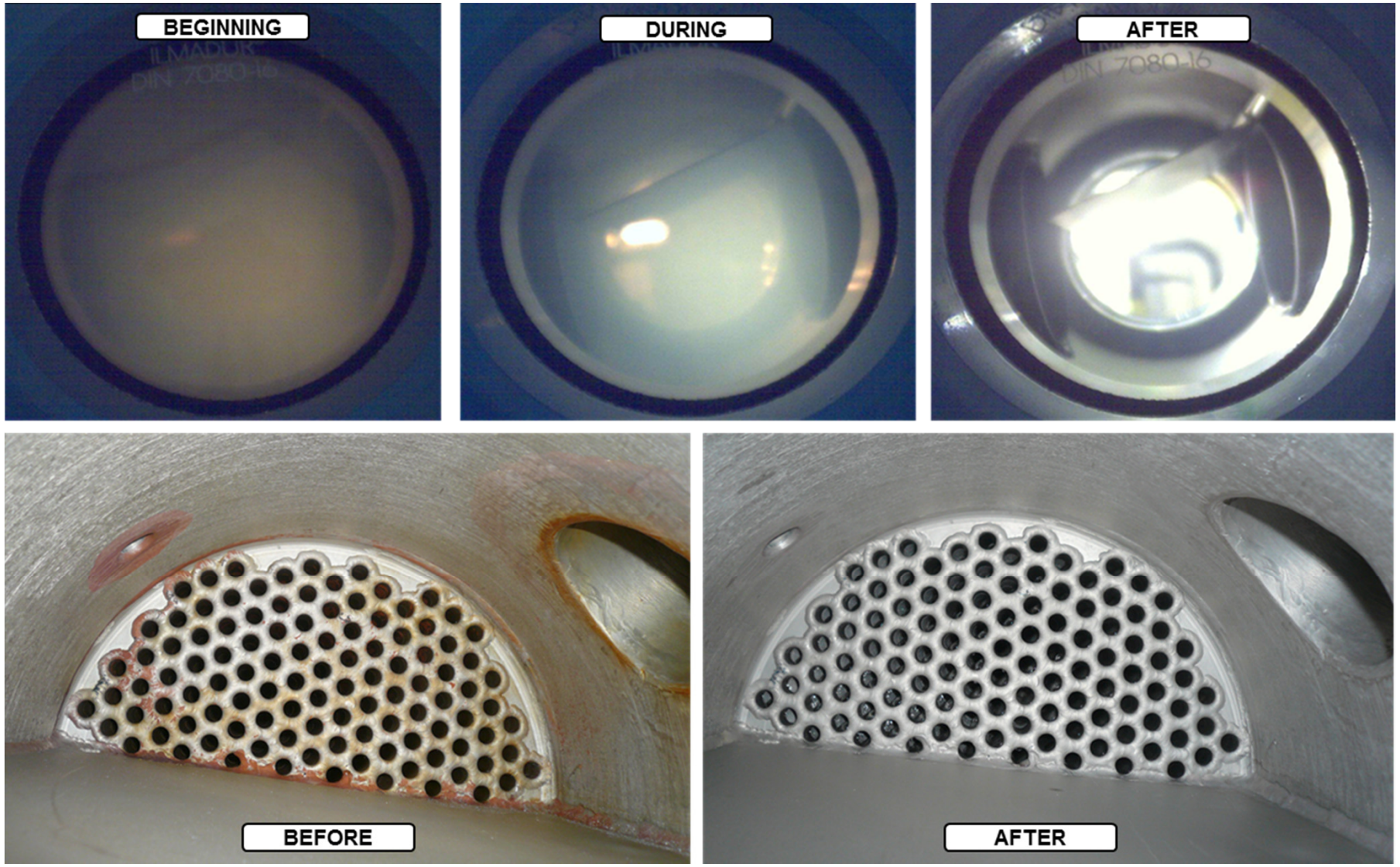
Effective removal of smearable contamination with CORD P



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Pictures: AREVA / EON

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Full System Decontamination in 2016: BWR KKK – Northern Germany

KRÜMMEL (KKK) 2016	
OEM	SIEMENS KWU (AREVA)
TYPE	BWR
OPERATED BY	VATTENFALL
CAPACITY	1402 MWe
OPERATION	1984 - 2011
CURRENTLY IN STAND STILL OPERATION	

DECON PROJECT HIGHLIGHTS:

- LARGEST BWR IN GERMANY
- MATERIAL MIX: STAINLESS STEEL + CARBON STEEL
- DECON OF RPV INTERNALS VERY SUCCESSFUL
- ADOPTION OF HIGH CAPACITY RESINS ENABLES SIGNIFICANT IMPROVEMENT IN WASTE VOLUME REDUCTION
- DETAILED RESULTS TO BE PRESENTED TOGETHER WITH VATTENFALL IN MARCH 2017

Picture: VATTENFALL

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Full System Decontamination in 2016: PWR KKG – Southern Germany

GRAFENRHEINFELD (KKG) 2016	
OEM	SIEMENS KWU (AREVA)
TYPE	PWR - 4 LOOP
OPERATED BY	PREUSSEN-ELEKTRA
CAPACITY	1275 MWe
OPERATION	1975 - 2015
D&D STRATEGY	EARLY - FSD

DECON PROJECT HIGHLIGHTS:

- FIRST PLANT IN GERMANY TO REACH NON-IMMEDIATE END OF OPERATION AFTER NUCLEAR-PHASE OUT
- FIRST PLANT IN GERMANY TO PERFORM 2 FSDs
- IMPLEMENTATION OF LESSONS LEARNED FROM ALL FORMER PROJECTS
- PRESENTATION OF DETAILED RESULTS SOON - TO BE ANNOUNCED

Picture: PREUSSEN-ELEKTRA

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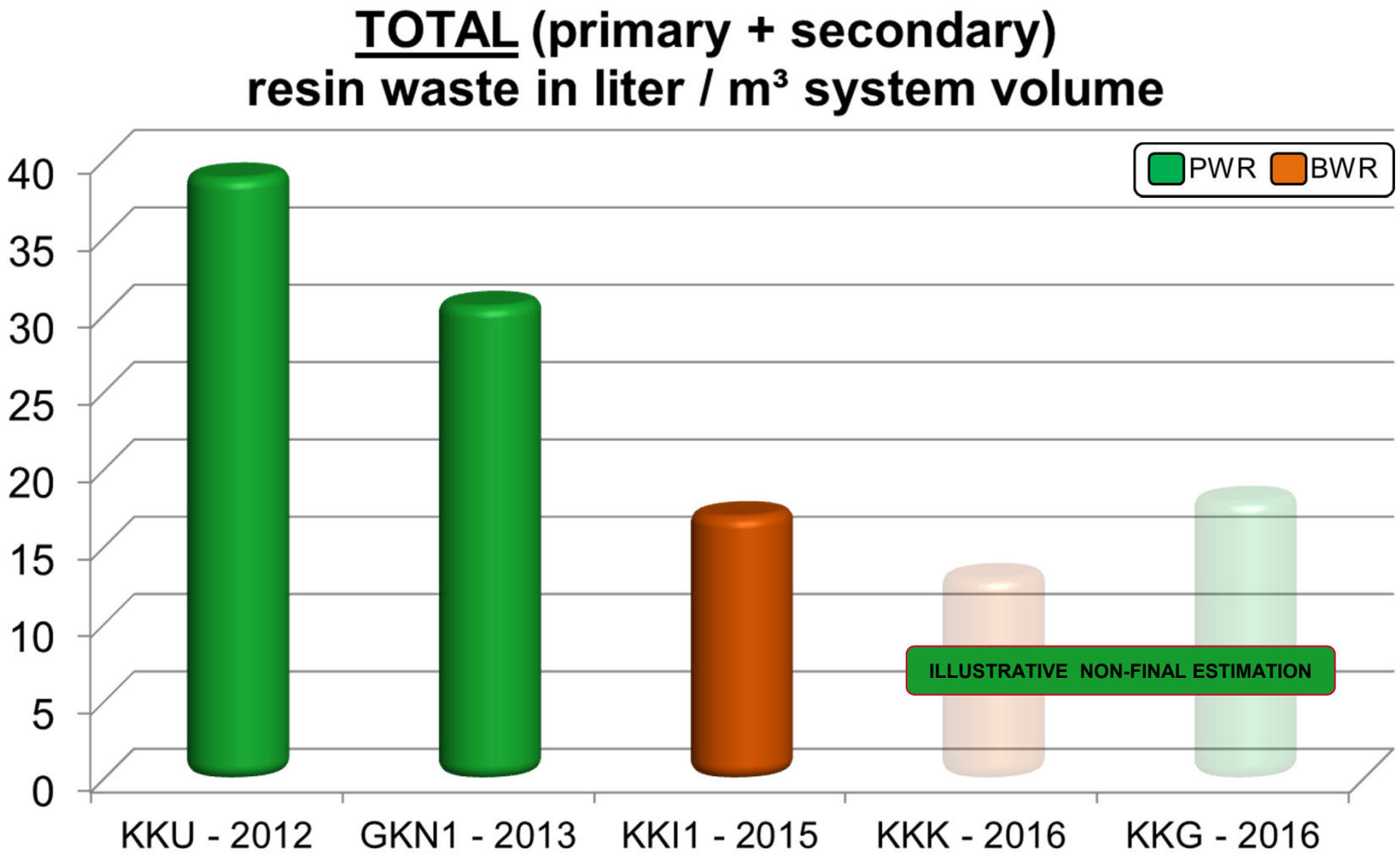
Further waste volume reduction achieved
through improved ion exchange resin management



Development of waste treatment processes based on chemical decontamination technology

- **AREVA's decontamination technology generates chelate-free waste with exactly the same composition and characteristics as operational waste**
- **No new disposal path needs to be invented or developed**
- **Several waste treatment processes have been developed as a spinoff of AREVA's decontamination technology**
  - RADIONUCLIDE AND METAL STRIPPING FROM SPENT RESINS (REUSE, RECLASSIFICATION TO LOWER WASTE DISPOSAL CATEGORY)
  - RECOVERY OF RADIONUCLIDES FOR USE IN INDUSTRIAL OR MEDICAL APPLICATIONS (COBALT-60, **CARBON-14**)
  - CHEMICAL IX-RESIN MINERALIZATION UNTIL CARBON FREE
  - SOLIDIFICATION OF WASTES
  - BORIC ACID REMOVAL
  - MINIMIZATION OF LIQUID WASTE VOLUME

A mature, reliable and efficient technology for achieving very significant dose reductions

- **Chemical decontamination is a mature, reliable technology for preparation for dismantlement**
- **Very significant dose savings can be achieved in a timely manner in a very efficient and secure way**
- **AREVA has accumulated very significant operational experience**
  - GROUP OF SCIENTISTS, ENGINEERS AND TECHNICIANS WITH EXCLUSIVE DEDICATION TO APPLYING & IMPROVING CHEMICAL DECONTAMINATION
  - YOUNG, VERY EXPERIENCED TEAM (AVG. 40Y OLD, 10Y EXPERIENCE)
  - CAPABLE OF PERFORMING LARGE, COMPLEX LONG TIME PROJECTS FROM THE BEGINNING TO THE END
  - LARGE SPECIALIZED EQUIPMENT POOL, FIELD TESTED AND CONSTANTLY IMPROVED AND OPTIMIZED, FOR ALL KINDS OF PROJECTS: FROM SINGLE COMPONENT DECON TO FULL SYSTEM DECONTAMINATION
  - INTERNATIONAL EXPERIENCE IN REACTORS FROM ALL CONSTRUCTORS AND DESIGNS

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End of presentation

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CHEMICAL PROCESS SUPERVISOR
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Sarpsborg, February 8th 2017

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