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
AREVAs Worldwide Experience in Chemical Decontamination covering all main NPP Designs

- Europe 1991-2015: 9 FSDs prior to Decommissioning 1994-2016: 4 FSDs in operating NPPs
- USA 1998: 1 FSD for Decommissioning
- Japan 1998-2011: 5 FSDs in operating BWRs

- FSD in operating NPPs
- FSD & decon prior to decommissioning
- Since 1976 > 500 decontaminations of pumps and systems
The Chooz A dismantlement 2011/2012: Pioneering D&D in France

CHOOZ-A 2011/12

<table>
<thead>
<tr>
<th>OEM</th>
<th>WESTINGHOUSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE</td>
<td>PWR - 4 LOOP</td>
</tr>
<tr>
<td>OPERATED BY</td>
<td>EDF</td>
</tr>
<tr>
<td>CAPACITY</td>
<td>305 MWe</td>
</tr>
<tr>
<td>OPERATION</td>
<td>1967 - 1993</td>
</tr>
<tr>
<td>D&amp;D STRATEGY</td>
<td>SAFSTOR - COMPONENTS</td>
</tr>
</tbody>
</table>

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

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

- 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

<table>
<thead>
<tr>
<th>BEFORE</th>
<th>AFTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 000 Bq/cm²</td>
<td>40 Bq/cm² (CORD)</td>
</tr>
<tr>
<td>40 000 Bq/cm²</td>
<td>2 000 Bq/cm² (other treatment for plugged tubes)</td>
</tr>
<tr>
<td>700 µSv/h</td>
<td>1 µSv/h</td>
</tr>
<tr>
<td>450 GBq Co60</td>
<td>0.65 GBq Co60</td>
</tr>
</tbody>
</table>

Pictures: EdF
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

AREVA NP
### Full System Decontamination in 2012: PWR KKU – Northern Germany

**UNTERWESER (KKU) 2012**

<table>
<thead>
<tr>
<th>OEM</th>
<th>SIEMENS KWU (AREVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE</td>
<td>PWR - 4 LOOP</td>
</tr>
<tr>
<td>OPERATED BY</td>
<td>EON (PREUSSEN ELEKTRA)</td>
</tr>
<tr>
<td>CAPACITY</td>
<td>1410 MWe</td>
</tr>
<tr>
<td>OPERATION</td>
<td>1979 - 2011</td>
</tr>
<tr>
<td>D&amp;D STRATEGY</td>
<td>EARLY - FSD</td>
</tr>
</tbody>
</table>

**DECON PROJECT HIGHLIGHTS:**

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

"FROM A TECHNICAL POINT OF VIEW, THE PLANT COULD RETURN TO OPERATION"
Full System Decontamination in 2013: PWR GKN1 – Southern Germany

NECKARWESTHEIM-1 (GKN1) 2013

<table>
<thead>
<tr>
<th>OEM</th>
<th>SIEMENS KWU (AREVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE</td>
<td>PWR - 3 LOOP</td>
</tr>
<tr>
<td>OPERATED BY</td>
<td>EnBW</td>
</tr>
<tr>
<td>CAPACITY</td>
<td>860 MWe</td>
</tr>
<tr>
<td>OPERATION</td>
<td>1976 - 2011</td>
</tr>
<tr>
<td>D&amp;D STRATEGY</td>
<td>EARLY - FSD</td>
</tr>
</tbody>
</table>

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

Picture: EnBW
### Full System Decontamination KKU & GKN1
distribution of contact dose rates before / after FSD

#### KKU 2012

<table>
<thead>
<tr>
<th>Dose Rate (mSv/h)</th>
<th>Number of Measuring Points Before FSD</th>
<th>Number of Measuring Points After FSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.005</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>&lt;0.01</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>&lt;0.05</td>
<td>30</td>
<td>44</td>
</tr>
<tr>
<td>&lt;0.1</td>
<td>22</td>
<td>14</td>
</tr>
<tr>
<td>&lt;0.5</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>&lt;1</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>&lt;2</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>&lt;5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>&lt;10</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>&lt;20</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

#### GKN1 2013

<table>
<thead>
<tr>
<th>Dose Rate (mSv/h)</th>
<th>Number of Measuring Points Before FSD</th>
<th>Number of Measuring Points After FSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.005</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>&lt;0.01</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>&lt;0.05</td>
<td>4</td>
<td>35</td>
</tr>
<tr>
<td>&lt;0.1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>&lt;0.5</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>&lt;1</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>&lt;2</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>&lt;5</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>&lt;10</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>&lt;20</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
Full System Decontamination KKU & GKN1
distribution of contact dose rates before / after FSD

BEFORE FSD

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)

FSD GKN1 2013
(66 MEASURING POINTS)

COLLECTIVE DOSE FOR ALL FSD ACTIVITIES:

75 mSv

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

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

COLLECTIVE DOSE FOR ALL FSD ACTIVITIES: 75 mSv

INVEST 7.5 REM, SAVE 10 000 REM
Full System Decontamination in 2015: BWR KKI1 – Southern Germany

**ISAR-1 (KKI1) 2015**

<table>
<thead>
<tr>
<th>OEM</th>
<th>SIEMENS KWU (AREVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE</td>
<td>BWR</td>
</tr>
<tr>
<td>OPERATED BY</td>
<td>EON (PREUSSEN-ELEKTRA)</td>
</tr>
<tr>
<td>CAPACITY</td>
<td>912 MWe</td>
</tr>
<tr>
<td>OPERATION</td>
<td>1977 - 2011</td>
</tr>
<tr>
<td>D&amp;D STRATEGY</td>
<td>EARLY - FSD</td>
</tr>
</tbody>
</table>

**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 ✓**

AREVA NP
Process engineering for FSD in KKI1 successful by working together

The excellent cooperation between teams and fantastic contributions such as these from the operating personnel of these plants made all these projects so successful!
Full System Decontamination KKI 1
BWR KKI 1 – Steam Dryer & Water Separator Results

STEAM DRYER BEFORE FSD IN UNDERWATER STORAGE (2012)

STEAM DRYER IN DRY STORAGE LOCATION AFTER FSD (2015)

NO AIRBORNE RELATED ACTIVITY DETECTED

FOLLOW UP OF DRY CUTTING TECHNIQUES FOR STEAM DRYER BY KKI

STEAM DRYER DF = 46

WATER SEPARATOR BEFORE FSD IN UNDERWATER STORAGE (2012)

WATER SEPARATOR ABOVE WATER LEVEL AFTER FSD (2015)

Pictures: EON
Effective removal of smearable contamination with CORD P

BEFORE

DURING

AFTER

BEFORE

AFTER

Pictures: AREVA / EON
Full System Decontamination in 2016: BWR KKK – Northern Germany

**KRÜMMEL (KKK) 2016**

<table>
<thead>
<tr>
<th><strong>OEM</strong></th>
<th>SIEMENS KWU (AREVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TYPE</strong></td>
<td>BWR</td>
</tr>
<tr>
<td><strong>OPERATED BY</strong></td>
<td>VATTENFALL</td>
</tr>
<tr>
<td><strong>CAPACITY</strong></td>
<td>1402 MWe</td>
</tr>
<tr>
<td><strong>OPERATION</strong></td>
<td>1984 - 2011</td>
</tr>
</tbody>
</table>

**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

AREVA NP
Full System Decontamination in 2016: PWR KKG – Southern Germany

**GRAFENRHEINFELD (KKG) 2016**

<table>
<thead>
<tr>
<th>OEM</th>
<th>Siemens KWU (AREVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE</td>
<td>PWR - 4 LOOP</td>
</tr>
<tr>
<td>OPERATED BY</td>
<td>PREUSSEN-ELEKTRA</td>
</tr>
<tr>
<td>CAPACITY</td>
<td>1275 MWe</td>
</tr>
<tr>
<td>OPERATION</td>
<td>1975 - 2015</td>
</tr>
<tr>
<td>D&amp;D STRATEGY</td>
<td>EARLY - FSD</td>
</tr>
</tbody>
</table>

**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
Further waste volume reduction achieved through improved ion exchange resin management

**TOTAL** (primary + secondary)

resin waste in liter / m³ system volume

ILLUSTRATIVE NON-FINAL ESTIMATION
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
End of presentation

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
Any reproduction, alteration, transmission to any third party or publication in whole or in part of this document and/or its content is prohibited unless AREVA NP has provided its prior and written consent.

This document and any information it contains shall not be used for any other purpose than the one for which they were provided. Legal action may be taken against any infringer and/or any person breaching the aforementioned obligations.