Operational Decommissioning Experiences in Germany

7th International Summer School on Nuclear Decommissioning and Waste Management
Ispra, Italy, September 14th-18th, 2015
Przemyslaw Imielski
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH
Germany

Contents

Analysing the current nuclear situation in Germany
- German phase-out decision
- Overview on decommissioning projects in Germany
- The German regulatory system

Lessons learned from past and present decommissioning projects in Germany
- Decommissioning experiences
  - Phased approach
  - Industrial development at the site
  - Large component removal
  - Clearance

Examining the current challenges (and future opportunities)
German Phase-out Decision

After the events at Japanese Nuclear Power Plant (NPP) Fukushima Daiichi in March 2011 the German government decided to

- "end the use of nuclear energy for the commercial generation of electricity at the earliest possible time — by gradually phasing it out."
- This decision resulted in an Amendment of the German Atomic Energy Act of July 31st, 2011
  - Withdrawing the authorisation to operate an installation for the fission of nuclear fuel for the commercial production of electricity for the seven oldest NPPs and NPP Krümmel on August 6th, 2011
  - Setting end-dates for the authorisation for the remaining 9 NPPs on a step-by-step-basis until 2022 at the latest

---

### Timetable for shut down of commercial reactors in operation

<table>
<thead>
<tr>
<th>Name</th>
<th>Abbrev.</th>
<th>Reactor type</th>
<th>Power MW&lt;sub&gt;e&lt;/sub&gt;</th>
<th>Date of final shut down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grafenrheinfeld</td>
<td>KKG</td>
<td>PWR</td>
<td>1345</td>
<td>31.12.2015*</td>
</tr>
<tr>
<td>Gundremmingen B</td>
<td>KRB-II-B</td>
<td>BWR</td>
<td>1344</td>
<td>31.12.2017</td>
</tr>
<tr>
<td>Philippsburg 2</td>
<td>KKP 2</td>
<td>PWR</td>
<td>1468</td>
<td>31.12.2019</td>
</tr>
<tr>
<td>Grohnde</td>
<td>KWG</td>
<td>PWR</td>
<td>1430</td>
<td>31.12.2021</td>
</tr>
<tr>
<td>Gundremmingen C</td>
<td>KRB-II-C</td>
<td>BWR</td>
<td>1344</td>
<td>31.12.2021</td>
</tr>
<tr>
<td>Brokdorf</td>
<td>KBR</td>
<td>PWR</td>
<td>1480</td>
<td>31.12.2021</td>
</tr>
<tr>
<td>Isar 2</td>
<td>KKI 2</td>
<td>PWR</td>
<td>1485</td>
<td>31.12.2022</td>
</tr>
<tr>
<td>Emsland</td>
<td>KKE</td>
<td>PWR</td>
<td>1400</td>
<td>31.12.2022</td>
</tr>
<tr>
<td>Neckarwestheim 2</td>
<td>GKN 2</td>
<td>PWR</td>
<td>1400</td>
<td>31.12.2022</td>
</tr>
</tbody>
</table>

* Application for decommission license on 28.03.2014
Overview on Decommissioning Projects in Germany

Decommissioning of nuclear facilities in Germany – experiences since 1970th

- Prototype / Commercial Reactor
  - shut down / under decommissioning
  - decommissioning completed
- Research Reactor
  - shut down / under decommissioning
  - decommissioning completed
- Nuclear Fuel Cycle Facility
  - shut down / under decommissioning
  - decommissioning completed

Past and current decommissioning projects of prototype or commercial reactors
- Total: 19
- Removed: 3
- Under dismantling: 16
- Safe enclosure: 2
- Reactor types:
  - PWR
  - BWR
  - Fast breeder
  - High temperature gas cooled
  - Heavy water gas cooled
### Overview on Decommissioning Projects in Germany

Past and current decommissioning projects of **prototype or commercial reactors**

<table>
<thead>
<tr>
<th>Name</th>
<th>Abbrev.</th>
<th>Reactor type</th>
<th>Power MWₑ</th>
<th>Decom. started</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mehrzweckforschungsreaktor</td>
<td>MZFR</td>
<td>PWR/D₂O</td>
<td>57</td>
<td>1987</td>
<td>RS</td>
</tr>
<tr>
<td>Kompakte Natriumgekühlte Kernanlage</td>
<td>KNK II</td>
<td>SNR</td>
<td>21</td>
<td>1993</td>
<td>RS</td>
</tr>
<tr>
<td>Arbeitsgemeinschaft Versuchsreaktor Jülich</td>
<td>AVR</td>
<td>HTR</td>
<td>15</td>
<td>1994</td>
<td>RS</td>
</tr>
<tr>
<td>Greifswald 1-5</td>
<td>KGR 1-5</td>
<td>PWR/WWER</td>
<td>440</td>
<td>1995</td>
<td>RS</td>
</tr>
<tr>
<td>Rheinsberg</td>
<td>KKR</td>
<td>PWR/WWER</td>
<td>70</td>
<td>1995</td>
<td>RS</td>
</tr>
<tr>
<td>Würgassen</td>
<td>KWW</td>
<td>BWR</td>
<td>670</td>
<td>1997</td>
<td>RS</td>
</tr>
<tr>
<td>Mülheim-Kärlich</td>
<td>KMK</td>
<td>PWR</td>
<td>1302</td>
<td>2004</td>
<td>RS</td>
</tr>
<tr>
<td>Stade</td>
<td>KKS</td>
<td>PWR</td>
<td>672</td>
<td>2005</td>
<td>RS</td>
</tr>
<tr>
<td>Obrigheim</td>
<td>KWO</td>
<td>PWR</td>
<td>357</td>
<td>2008</td>
<td>RS</td>
</tr>
</tbody>
</table>

RS: release of site from regulatory control

---

### Overview on Decommissioning Projects in Germany

Past and current decommissioning projects of **prototype or commercial reactors**

<table>
<thead>
<tr>
<th>Name</th>
<th>Abbrev.</th>
<th>Reactor type</th>
<th>Power MWₑ</th>
<th>Decom. started</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Niederaichbach</td>
<td>KKN</td>
<td>DRR</td>
<td>106</td>
<td>1975</td>
<td>RS in 1994</td>
</tr>
<tr>
<td>Versuchsatomkraftwerk Kahl</td>
<td>VAK</td>
<td>BWR</td>
<td>16</td>
<td>1988</td>
<td>RS in 2010</td>
</tr>
<tr>
<td>Gundremmingen-A</td>
<td>KRB-A</td>
<td>BWR</td>
<td>250</td>
<td>1983</td>
<td>RCA KRB-II</td>
</tr>
<tr>
<td>Lingen</td>
<td>KWL</td>
<td>BWR</td>
<td>252</td>
<td>1985</td>
<td>SE since 1988</td>
</tr>
<tr>
<td>Thorium-Hochtemperaturreaktor</td>
<td>THTR-300</td>
<td>HTR</td>
<td>308</td>
<td>1993</td>
<td>SE since 1997</td>
</tr>
</tbody>
</table>

RCA: radiation controlled area, new license
SE: safe enclosure
RS: release of site from regulatory control
Overview on Decommissioning Projects in Germany

Outlook for prototype or commercial reactors
(Finally shut down, no decommissioning license issued)

<table>
<thead>
<tr>
<th>Name</th>
<th>Abbrev.</th>
<th>Reactor type</th>
<th>Power MW_e</th>
<th>Date of application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lingen</td>
<td>KWL</td>
<td>BWR</td>
<td>252</td>
<td>15.12.2008*</td>
</tr>
<tr>
<td>Isar-1</td>
<td>KKI 1</td>
<td>BWR</td>
<td>912</td>
<td>04.05.2012</td>
</tr>
<tr>
<td>Unterweser</td>
<td>KU</td>
<td>BWR</td>
<td>1410</td>
<td>04.05.2012**</td>
</tr>
<tr>
<td>Biblis-A</td>
<td>KWB A</td>
<td>PWR</td>
<td>1225</td>
<td>06.08.2012</td>
</tr>
<tr>
<td>Biblis-B</td>
<td>KWB B</td>
<td>PWR</td>
<td>1300</td>
<td>06.08.2012</td>
</tr>
<tr>
<td>Brunsbüttel</td>
<td>KKB</td>
<td>BWR</td>
<td>806</td>
<td>01.11.2012</td>
</tr>
<tr>
<td>Neckarwestheim-1</td>
<td>GKN 1</td>
<td>PWR</td>
<td>840</td>
<td>24.04.2013</td>
</tr>
<tr>
<td>Philippsburg-1</td>
<td>KKP 1</td>
<td>BWR</td>
<td>926</td>
<td>24.04.2013</td>
</tr>
<tr>
<td>Krümmel</td>
<td>KKK</td>
<td>BWR</td>
<td>1402</td>
<td>24.08.2015</td>
</tr>
<tr>
<td>Grafenrheinfeldfeld</td>
<td>KKG</td>
<td>PWR</td>
<td>1345</td>
<td>28.03.2014***</td>
</tr>
</tbody>
</table>

* Dismantling after safe enclosure
** Application changed on 20.12.2013
*** Date of final shut down 31.12.2015

Past and current decommissioning projects of research reactors
- Total: 35
- Removed: 29
- Under dismantling: 6
- Safe enclosure: 2
- Finally shut down, no decommissioning license issued: 4
- Variety of types of research reactors
  - Argonaut type
  - Critical assembly
  - Educational reactors
  - Liquid homogenous reactor
  - Propulsion reactor
  - Pool reactor (incl. TRIGA type)
  - Heavy water reactor (incl. DIDO type)
Overview on Decommissioning Projects in Germany

Past and current decommissioning projects of nuclear fuel cycle facilities
- Total: 11
- Removed: 10
- Safe enclosure: 0
- Under dismantling: 1

Former storage building for vitrification waste at WAK with additional building for remote dismantling and packaging of decommissioning waste

Slave support system for remote dismantling at WAK

The German Regulatory System

Hierarchical structure of the regulations

The German Regulatory System

Brief overview on the (Federal) Decommissioning Guide

- **Objective:**
  - harmonize the procedures among all Länder authorities
  - Comprehensive collection of existing requirements and recommendations on the decommissioning of nuclear facilities in Germany
    - Jointly applied by all Länder authorities
    - Strong focus on procedural licensing and supervisory aspects
  - Contains among others
    - Comprehensive list of individual elements of the guidelines, recommendations and safety standards to be applied
    - Description of fundamental factors to be considered during determining the decommissioning strategy
    - Aspects to be considered during the safety assessment
  - Available also in English language

(Federal) Decommissioning Guide represents good practice in Germany from regulatory point of view

Regulation of decommissioning in Germany

- § 7 (3) of the German Atomic Energy Act
  The decommissioning of an installation [...] as well as the safe confinement of an installation, or the dismantling of an installation or of parts thereof shall require a license [...].

View point: phase in lifetime of a facility

- Final shutdown
- Granting decommissioning licence
- Release from nuclear regulatory control
- Decommissioning: about 10 years
- Operating licence
- Decommissioning licence
- Power operation
- Post-operational phase
- ”Greenfield”
The German Regulatory System

Basic requirements
- The German Atomic Energy Act allows either
  - to immediate dismantle or
  - to dismantle after a safe enclosure a nuclear facility

Note: no entombment (near surface disposal) is allowed
- The operator of a nuclear facility is fully responsible for the decommissioning and dismantling of a nuclear facility
  - He decides on the decommissioning strategy and the timeframe
  - He decides on the scope of a license he applies for

Note: the operator has to ensure at any time the safety of the facility and any precautionary measures are taken
- Decommissioning and dismantling are subject to one or more licenses
- Decommissioning activities are subject to an intensive regulatory supervision, involving technical experts and on-site presence during the full project

Process of licensing

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB)
- Advisory bodies (ESK, SSK, RSK)
- Experts and expert organizations (GRS)

Other authorities of the Land (Federal State)
- Experts and Expert organizations (TÜV)

Licensing authority of the Land (Federal State)

Other federal authorities

General public

Applicant / Licensee

Application documents

- Draft of the license
- Application documents
- Evaluation reports by the authorized experts

License

Statement of BMUB on the draft of the license „Agreement on the license“
Decommissioning Experiences – Phased Approach

- Typically large decommissioning projects
  - are divided into phases (corresponding to large work packages)
  - work from “outside to inside”
    - Phase 1: blue
    - Phase 2: yellow / orange
    - Phase 3: red

- A phase
  - corresponds to a large work package
  - can be reflected by an individual license

- Advantages
  - allows to structure large complex technical systems
  - allows to gain further information needed for later work packages
  - allows flexibility in adapting changes in future phases not licensed yet

A typical & recent decommissioning project – decommissioning of Stade NPP

- Design features
  - Reactor type: PWR
  - Electrical power: 672 MWe
  - Operator: Kernkraftwerk Stade GmbH & Co. KG

- Decommissioning “features”
  - Decommissioning due to economic reasons
  - 4 phases approach on immediate dismantling
  - End-state: release of the site for unrestricted use, proposed for 2015
  - Inventory: total of $10^{17}$ Bq, mobile contamination of $10^{13}$ Bq
Stade NPP Decommissioning: Content of the phase 1
- Removal of contaminated systems and components
- Objectives:
  - Free space for later dismantling work
  - Preparation of later dismantling work
  - Removal of systems and components

Stade NPP Decommissioning: Content of the phase 2
- Removal of large components, including
  - Pipes and pumps of the primary circuit
  - Steam generator (transfer to Studsvik for processing)
Decommissioning Experiences – Phased Approach

- Stade NPP Decommissioning: Content of the phase 3
  - Removal of activated systems and components
    - Core internals
    - Spent fuel pond internals
    - In-situ dismantling of reactor vessel
      - Cutting of large parts
      - Drum size cutting in former spent fuel pond
    - Biological shielding
  - …

© E.on Kernkraft GmbH

Decommissioning Experiences – Phased Approach

- Stade NPP Decommissioning: Content of the phase 4
  - Removal of remaining systems and components
    - Fuel load machine
    - Reactor crane
    - Ventilation system
    - Water treatment system
  - Preparation for clearance for unrestricted use

© E.on Kernkraft GmbH
Decommissioning Experiences – Phased Approach

Example of 4 Phases @ Stade NPP

- **Operational Phase**
  - Post-operational phase
  - Residual operations and dismantling

- **Phase 1**
  - Licensing of and supervision on the decommissioning

- **Phase 2**
  - Release from regulatory control

- **Phase 3**
  - Dismantling of non-nuclear facilities

- **Phase 4**
  - Construction & operation of an interim storage facility for rad. waste

Year of decommissioning: 2011

© E.on Kernkraft GmbH

---

Decommissioning Experiences – Industrial Development at the Site

- **Decommissioning of the Greifswald NPPs**
  - Design features
    - Reactor type: 4 WWER-440/W-230
    - 2 WWER-440/W-213
    - 2 more planned
    - Electrical power: 2 x 220 MWe per unit
    - Operator: EWN GmbH

- **Decommissioning “features”**
  - Decommissioning due to technical reasons after German reunification
  - 8 phases approach on immediate dismantling
  - End-state: release of the site for (conventional) re-use
  - Inventory: total of $4 \times 10^{17}$ Bq

© EWN GmbH

---

5th International Summer School on Nuclear Decommissioning and Waste Management, 2015
Decommissioning Experiences – Large Component Removal

- Dismantling of large components – German practice shows following options
  - In-situ dismantling
  - Partial in-situ dismantling
    - Post-processing on-site or off-site
  - Removal and ex-situ dismantling (typically for components of metal)
    - On-site dismantling
      - Immediate dismantling
      - Deferred dismantling
        (if appropriate: dismantling after decay storage)
    - Off-site dismantling
      - At external service providers
        (cutting, decontamination / melting, clearance – in a foreign country: still according to German requirements, return of material and radioactive waste)

Examples of large component removal for off-site dismantling

- KWO steam generator shipment for interim storage at Greifswald NPP
- KGR reactor vessel removal to Interim Storage Facility North

© ndr.de
© B. Jünger
© nadir.org
© R. Borchardt, G. Hillebrecht, EWN. 2010 Annual Meeting of German Nuclear Society
Character of “Clearance”
- Administrative act which effects the exemption of radioactive substances and any movable goods, of buildings, soil areas, installations or parts of installations which are activated or contaminated by radioactive substances and which originate from practices from regulatory control
- Clearance of radioactive substances and movable goods, buildings, soil areas, facilities or parts of facilities which are activated or contaminated material, can be granted by the regulatory body ("license") only if relevant radiological requirements are fulfilled
- Regulated in detail § 29 of the German Radiation Protection Ordinance (StrlSchV)

Basic radiological requirement / concept: “De Minimis Principle” radioactive activation and contamination of the material, ... to be cleared, shall be such, that the exposure of a member of the public is no more than about 10µSv/a

For simplification and to avoid long lasting calculations: for a set of radionuclides clearance levels have been calculated and are available as appendix III of StrlSchV

Different clearance levels for different clearance options:

<table>
<thead>
<tr>
<th>unrestricted clearance (&quot;use as you like&quot;):</th>
<th>clearance for specific purposes (&quot;the use is predicted&quot;):</th>
</tr>
</thead>
<tbody>
<tr>
<td>solid material</td>
<td>solid material for disposal (100t, 1000t)</td>
</tr>
<tr>
<td></td>
<td>incineration (100t, 1000t)</td>
</tr>
<tr>
<td>liquids</td>
<td>liquids for disposal in a waste incineration plant</td>
</tr>
<tr>
<td>building rubble and excavated soil with an expected mass of more than 1,000 t/a</td>
<td>buildings for demolition</td>
</tr>
<tr>
<td>sites</td>
<td>scrap metal for recycling</td>
</tr>
<tr>
<td>buildings for reuse and further use</td>
<td></td>
</tr>
</tbody>
</table>
Decommissioning Experiences – Clearance

• Example on the masses from a recent decommissioning project

![Diagram showing materials categories: percentages and volumes](image)

<table>
<thead>
<tr>
<th>Area in Mg (megagrams)</th>
<th>Clearance</th>
<th>Controlled re-use</th>
<th>Radiactive waste</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear area</td>
<td>134,605 (82.2%)</td>
<td>545 (0.4%)</td>
<td>2,941 (2.0%)</td>
<td>162,151 (100%)</td>
</tr>
<tr>
<td>Non-nuclear area</td>
<td>272,100</td>
<td>-</td>
<td>-</td>
<td>272,100</td>
</tr>
<tr>
<td>Total</td>
<td>394,705</td>
<td>545</td>
<td>2,941</td>
<td>399,650</td>
</tr>
</tbody>
</table>

© E.ON Kernkraft GmbH
Stade NPP

Current challenges

Decommissioning of NPPs with fuel elements still present

<table>
<thead>
<tr>
<th>Name</th>
<th>Abbrev.</th>
<th>Storage of fuel elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neckarwestheim 1</td>
<td>GKN 1</td>
<td>Cooling pond</td>
</tr>
<tr>
<td>Philippsburg 1</td>
<td>KKP 1</td>
<td>Cooling pond</td>
</tr>
<tr>
<td>Isar 1</td>
<td>KKI 1</td>
<td>Cooling pond</td>
</tr>
<tr>
<td>Biblis Block A</td>
<td>KWB A</td>
<td>Cooling pond</td>
</tr>
<tr>
<td>Biblis Block B</td>
<td>KWB B</td>
<td>Cooling pond</td>
</tr>
<tr>
<td>Unterweser</td>
<td>KKH</td>
<td>Cooling pond</td>
</tr>
<tr>
<td>Brunsbüttel</td>
<td>KKB</td>
<td>Reactor pressure vessel and cooling pond</td>
</tr>
<tr>
<td>Krümmel</td>
<td>KKK</td>
<td>Cooling pond</td>
</tr>
</tbody>
</table>

• (Re-)Classification of systems
• Demonstrating absence of impact when dismantling structures, systems and components
Current challenges

Waste management
- Timeline of waste generation
- Clearance options
- Treatment and conditioning capacities
- Long-term interim storage of fuel and decommissioning waste

Knowledge management
- Maintenance of competence at all levels
  - Operators
  - Regulatory body
  - Technical support organisations

Summary

- In Germany a large number of decommissioning projects was successfully performed

- Recent decommissioning experiences relate among others to
  - Phased approach
  - Industrial development at the site
  - Large component removal
  - Clearance

- Challenges
  - Fuel elements still present
  - Waste management
  - Knowledge Management
Thank you for your attention!
Any Questions?