Decommissioning of RWE nuclear power plants

Prof. Gerd Jaeger
### Overview of German nuclear power plants

#### Table: Power plants and their details

<table>
<thead>
<tr>
<th>Power plant</th>
<th>Net capacity MW</th>
<th>Commercial commissioning</th>
<th>Closure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biblis A</td>
<td>1,167</td>
<td>1975</td>
<td></td>
</tr>
<tr>
<td>Neckarwestheim I</td>
<td>785</td>
<td>1976</td>
<td></td>
</tr>
<tr>
<td>Biblis B</td>
<td>1,227</td>
<td>1977</td>
<td></td>
</tr>
<tr>
<td>Brunsbuettel</td>
<td>771</td>
<td>1977</td>
<td></td>
</tr>
<tr>
<td>Isar 1</td>
<td>878</td>
<td>1979</td>
<td></td>
</tr>
<tr>
<td>Unterweser</td>
<td>1,345</td>
<td>1979</td>
<td></td>
</tr>
<tr>
<td>Philippsburg 1</td>
<td>890</td>
<td>1980</td>
<td></td>
</tr>
<tr>
<td>Krümmel</td>
<td>1,346</td>
<td>1984</td>
<td></td>
</tr>
<tr>
<td>Grafenrheinfeld</td>
<td>1,275</td>
<td>1982</td>
<td>31.12.2015</td>
</tr>
<tr>
<td>Gundremmingen B</td>
<td>1,284</td>
<td>1984</td>
<td>31.12.2017</td>
</tr>
<tr>
<td>Philippsburg 2</td>
<td>1,392</td>
<td>1985</td>
<td>31.12.2019</td>
</tr>
<tr>
<td>Grohnde</td>
<td>1,360</td>
<td>1985</td>
<td></td>
</tr>
<tr>
<td>Gundremmingen C</td>
<td>1,288</td>
<td>1985</td>
<td>31.12.2021</td>
</tr>
<tr>
<td>Brokdorf</td>
<td>1,410</td>
<td>1986</td>
<td>4,058 MW</td>
</tr>
<tr>
<td>Isar 2</td>
<td>1,400</td>
<td>1988</td>
<td>31.12.2022</td>
</tr>
<tr>
<td>Emsland</td>
<td>1,329</td>
<td>1988</td>
<td>4,039 MW</td>
</tr>
<tr>
<td>Neckarwestheim II</td>
<td>1,310</td>
<td>1989</td>
<td></td>
</tr>
</tbody>
</table>

**Total capacity:** 20,457 MW

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**Map:**
- **RWE power plants:** Biblis, Neckarwestheim, Philippsburg, Grohnde, Isar, Emsland, Gundremmingen, Brunsbüttel, Unterweser, Krümmel, Brokdorf

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*Note: Immediate closure of 8,409 MW capacity.*
What is Decommissioning?

- Decommissioning is the generic term for *all decommissioning relevant activities till the end state* (e.g. green field) has been reached.

  (Interpretation from nuclear industry and general linguistic usage)

- The Atomic law uses the term „Decommissioning“ *in the legal sense for the final shut down of a nuclear facility.*
What are the special challenges of decommissioning?

> NPPs in multiyear post-operation phase legally stay under their operating license.

> Decommissioning license necessary to start major dismantling works.

> Availability of vital safety functions in post-operation and dismantling phase under strict supervision of regulators, experts and radiation protection.

> Minimization of the economic burden under preservation of adequate safety levels.
Example: Biblis nuclear power station

- Stack
- Cooling tower
- Concrete shell
- Containment steel liner
- Fuel rod loading machine
- Control rods
- Spent fuel pool
- Biological shield
- Reactor (Reactor pressure vessel)
- Emergency cooling / residual heat removal
- Reactor coolant lines
- Feedwater lines
- Steam lines
- Access lock
- Coolant pump
- Steam generator
- Turbine
- Condenser
- Generator
- Auxiliary facilities
Comparison to the decommissioning of a car
Decommissioning Options (I)
Definitions and Phases

Operation

Post operational Phase

Decommissioning

5-7 years

Deferred Dismantling (Safe Enclosure)

- For the time being, fuel elements are being cooled in pond storage facilities until they are suitable for dry-cask (CASTOR) storage on site

- Systems no longer needed to be shut down

- Treatment of operating materials and waste

15-20 years

Immediate Dismantling

- Partially dismantling
- Modification of infrastructure
- Care and Maintenance

- Dismantling planning and licensing
- Preparatory work

- Dismantling of contaminated and activated systems, structures and components
- Materials and waste management (treatment, conditioning, packaging)

Appr. 50 years (30 years of Safe Enclosure)

- Preparation of Safe Enclosure (SE)
- Operation of Safe Enclosure
- Transition from SE to dismantling
- Dismantling

- Dismantling of contaminated and activated systems, structures and components
- Materials and waste management (treatment, conditioning, packaging)

Materials and waste management (treatment, conditioning, packaging)
Decommissioning Options (II)
Cash flows and decision criteria

Immediate dismantling:
+ staff / know-how available
+ higher public acceptance
+ site available for future use
- Immediate cash-out
- Interim storage facilities necessary

Safe enclosure:
+ dose reduction by radioactive decay
+ costs postponed to the future
+ Independent from interim storage /final repository
- Irreversible loss of staff / know-how

NPVs of both options are almost the same
Cost assessment with the Decommissioning Reference Model (Germany)

- Inventory (e.g. masses and activity)
- Dismantling concept
- Decommissioning technologies
- Waste management concept
- ...

Results

- Masses
- Costs (over time)
- Radiation exposure
- Manpower requirements
- Time schedule
- ...

Provisions
## Nuclear Provisions

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1</td>
<td>Provisions for uncertain liabilities as per IAS 37</td>
</tr>
<tr>
<td>2</td>
<td>Public-law liabilities under Sec. 9a of the Germany Nuclear Energy Act:</td>
</tr>
<tr>
<td></td>
<td>&gt; „Polluter-pays-principle“</td>
</tr>
<tr>
<td></td>
<td>&gt; operator is responsible for waste-management and decommissioning</td>
</tr>
<tr>
<td></td>
<td>&gt; obligation by the operator, to deliver all radioactive waste to the state</td>
</tr>
<tr>
<td></td>
<td>&gt; Obligation by the state to build and operate a final repository</td>
</tr>
<tr>
<td>3</td>
<td>Provisions are made for RWE fiscal year 2010: €10,010 million</td>
</tr>
<tr>
<td></td>
<td>&gt; Disposal of spent nuclear fuel assemblies €4,831 million</td>
</tr>
<tr>
<td></td>
<td>Flasks, transport, conditioning, intermediate and final storage</td>
</tr>
<tr>
<td></td>
<td>&gt; Decommissioning of nuclear power plants €4,490 million</td>
</tr>
<tr>
<td></td>
<td>Post-operation phase, dismantling, removal, final storage</td>
</tr>
<tr>
<td></td>
<td>&gt; Disposal of radioactive operating waste (e.g. cleaning cloths, oils, resins) €689 million</td>
</tr>
<tr>
<td></td>
<td>Conditioning, flasks, intermediate and final storage</td>
</tr>
<tr>
<td>4</td>
<td>Inflation of current cost to the assumed disposal date by a set inflation rate; then discounting of the result back to today (discount rate 5.0%)</td>
</tr>
</tbody>
</table>
How the Size of the Provision is Determined

Schematic description

1. Total cost at the shut-down date
2. Escalation rate (specific cost increase)
3. Discount rate (discount to net present value)
4. Annual interest accretion

- 2010
- 2010
- 2011
- 2012
- 20..
Decommissioning Success Factors

- Shift from operational excellence to demolishing project
- Decommissioning is long term demolishing under strong restrictions regarding radiation protection
- Flexible dismantling and materials/waste management planning
  - Logistic and waste stream concept
  - Optimization of plant service operation, e.g. new modular systems for energy and media supply, ventilation and evaporation
  - Combination of off-site and on-site dismantling as well as waste treatment
- Optimisation of the licensing strategy
  (reduction of partial licences, in an extreme case only one overall licence)

RWE has a broad experience in all these fields
Conclusions:
- Extensive experiences from decommissioning of nuclear power plants since more than 2 decades
- Technical feasibility in compliance with safety and radiation protection standards is proofed
- All necessary technologies are available and were employed effective several times
- Qualified service providers are available
- Provision calculation model is established, well accepted and reliable

Experiences:

Immediate Dismantling
- Dismantling and Decontamination Technology Developments
- Waste treatment optimization
- Final release of buildings and site
- Future nuclear use (Technology Centre Unit A)

Deferred Dismantling
- Shut down and simplification of systems
- New “mobile” systems as surrogate for existing residual operation systems
- Partial release of buildings and terrain

NPP Kahl (BWR, 16 MWel)
Green Field (10/2010)
NPP Gundremmingen
Unit A (BWR, 250 MWel)
Dismantling completed
NPP Mülheim-Kärlich (PWR, 1,219 MWel)
Dismantling of contaminated parts
NPP Lingen (BWR, 240 MWel)
Transition from SE to dismantling

Experiences:
- Preparation and operation of safe enclosure
## Dismantling Process (I)
(Immediate dismantling)

<table>
<thead>
<tr>
<th></th>
<th>Title</th>
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<tbody>
<tr>
<td>1</td>
<td>Licence procedure</td>
</tr>
<tr>
<td>2</td>
<td>Dismantling of contaminated systems and components</td>
</tr>
<tr>
<td>3</td>
<td>Dismantling of activated components (RPV)</td>
</tr>
</tbody>
</table>
Dismantling Process (II)
(Immediate dismantling)

<table>
<thead>
<tr>
<th></th>
<th>Dismantling of biological shield</th>
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<tr>
<td>4</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Dismantling of remaining components</th>
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<tbody>
<tr>
<td>5</td>
<td></td>
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</tbody>
</table>
Dismantling Process (III)
(Immediate dismantling)

6
Decontamination and release of buildings

7
Pulling down of buildings
# Dismantling Process (IV)
(Immediate dismantling)

| 8 | Release of terrain (greenfield) |

![Image of people spreading something on the ground]

RWE Power AG · 13/9/2011
What happens after dismantling of components?
Decontamination and Stripping Techniques

Chemical/Electrochemical

Abrasive blasting

Grinding

Water jet

Subsequent conditioning of raw waste e.g. by incineration, super compaction or drying

Sources: Schmutz, Wirtgen, SINA
Established industry for materials and waste treatment

- Use of central capacities for the treatment of materials and/or the conditioning of the radioactive waste arising in the dismantling process

Sources: GNS, Studsvik, Siempelkamp, FZJ, EWN, Technologiezentrum Gundremmingen
## Responsibilities for Final Disposal

<table>
<thead>
<tr>
<th>Federal Government</th>
<th>Waste Producer</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Taking over the responsibility for permanent safety (repository as government's responsibility)</td>
<td>• Obligation for bearing the costs of all (!) necessary expenditures in terms of Final Disposal (&quot;polluter pays principle&quot;)</td>
</tr>
<tr>
<td>• Site selection &amp; exploration</td>
<td>• Obligation of waste delivery during repository operation</td>
</tr>
<tr>
<td>• Planning approval (licensing)</td>
<td></td>
</tr>
<tr>
<td>• Commissioning &amp; operation</td>
<td></td>
</tr>
<tr>
<td>• Decommissioning &amp; sealing</td>
<td></td>
</tr>
<tr>
<td>• Securing of compliance with the requirements in terms of adherence to limits</td>
<td>Wastes and packages:</td>
</tr>
<tr>
<td></td>
<td>• Conditioning and transport,</td>
</tr>
<tr>
<td></td>
<td>• Interim storage and delivery to the repository</td>
</tr>
<tr>
<td>Legal basis:</td>
<td>Legal basis:</td>
</tr>
<tr>
<td>• Atomic Law (AtG) §9 cl. 3</td>
<td>• Atomic Law</td>
</tr>
<tr>
<td></td>
<td>• Radiation Protection Ordinance</td>
</tr>
<tr>
<td></td>
<td>• Pre-payment provisions (EndlagerVIV)</td>
</tr>
</tbody>
</table>
Final Disposal – Volumes and masses

Final disposal volumes of conditioned waste from Decommissioning of all German nuclear power plants ca. 135,000 m³ (equivalent to a cube with an edge length of 51 m)

Example: typical PWR

Mass of radioactive waste for final disposal: ca. 2,5 % of total mass

Total mass of radiologically controlled area: 156.600 t
Final repository sites Konrad & Gorleben

<table>
<thead>
<tr>
<th>Konrad</th>
<th>Gorleben</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final repository for non-heat-generating waste (low- and intermediate-level waste, also medical waste)</td>
<td>Final repository for heat-generating waste (fuel rods, waste from reprocessing etc.)</td>
</tr>
<tr>
<td>▪ Former ore mine (1957 – 1976)</td>
<td>▪ Unused salt dome</td>
</tr>
<tr>
<td>▪ Consented for 303,000 m³ of waste packages, sufficient for all non-heat-generating waste from operation and decommissioning</td>
<td>▪ Begin of selection process from 140 salt domes in the 70ies, Federal government selected Gorleben in 1977</td>
</tr>
<tr>
<td>▪ Approx. 95% of total waste volume is non-heat-generating</td>
<td>▪ Exploration 1979 to 1999, moratorium in 2000</td>
</tr>
<tr>
<td>▪ Planning approval procedure started in 1982</td>
<td>▪ Moratorium ceased in 2010, next steps:</td>
</tr>
<tr>
<td>▪ Consent in 2002, last instance in 2007</td>
<td>- exploration continues</td>
</tr>
<tr>
<td>▪ Costs so far: 1.7 billion €*</td>
<td>- preliminary safety analysis</td>
</tr>
<tr>
<td>▪ Total costs: ca. 2.6 billion €</td>
<td>- international Peer Review</td>
</tr>
</tbody>
</table>

Commissioning before 2020 expected

Costs so far: 1.5 billion €**
Total costs: ca. 3.7 billion €

Commissioning in 2030ies possible

* Utility share: 64.4%
** Utility share: 96.5%
Conclusions

> The recent change in German energy policy leads to the final shutdown of 8 nuclear power plants, of which 2 belong to RWE

> Different decommissioning options
  - Immediate dismantling
  - Safe enclosure

> Provisions for decommissioning and final storage were made in sufficient amount

> RWE has a solid expertise in all important fields of decommissioning
  - Immediate Dismantling: VAK, Mülheim-Kärlich, Gundremmigen A
  - Safe enclosure: THTR, Lingen

> Industrial market for materials and waste treatment well established

> The availability of the final repository sites Konrad and Gorleben is an essential success factor