Decommissioning — a Global Perspective
Baker Forum Japan/US Roundtable

Eric Knox
AECOM, Management Services
Nuclear & Environment

7 April 2016
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– An Introduction to AECOM
  • Our “D4” Credentials
    o Decommissioning, Decontamination, Dismantling & Demolition

– Decommissioning – A Global Perspective
Built to deliver a better world
Who is AECOM? A Global, Integrated, Service Provider

150+ Countries

90,000 Employees

US$19.5 Billion Revenue

Making the world a better place
#1 Top 150 Global Design Firms
#1 Top 500 Design Firms
#1 Pure Design

1. Airports (Top 25)
1. Bridges (Top 25)
1. Chemical and Soil Remediation
1. Cogeneration (Top 10)
1. Co-Generation (Top 10)
1. Correctional Facilities (Top 10)
1. Dams and Reservoirs (Top 15)
1. Distribution and Warehouses (Top 5)
1. Environment Sanitary & Storm Sewers
1. Fossil Fuel (Top 25)
1. Government Offices (Top 25)
1. Hazardous Waste (Top 50)
1. Health Care (Top 25)
1. Highways (Top 25)
1. Hotel, Motels, and Convention Centers
1. Hydro Plants (Top 15)
1. Marine & Port Facilities (Top 10)
1. Mass Transit and Rail (Top 25)
1. Multi-Unit Residential (Top 15)
1. Solar Power (Top 10)

1. Sports (Top 10)
1. Transmission and Distribution Plants
1. Transmission Lines and Aqueducts
1. Wind Power (Top 10)
1. Auto Plants (Top 10)
2. Chemical Plants (Top 20)
2. Clean Air Act Compliance (Top 10)
2. Commercial Offices (Top 25)
2. Education (Top 25)
2. Electronic Assembly (Top 5)
2. Nuclear Plants (Top 20)
2. Pipelines (Top 25)
2. Power (Top 50)
2. Sewerage and Solid Waste (Top 50)
2. Site Assessment and Compliance
2. Wastewater Treatment Plants (Top 25)
2. Water Supply (Top 50)
3. Manufacturing (Top 50)
3. Manufacturing, Telecom & Ind Process
AECOM Growth History

Today —
• A Fortune 500 Firm — #343
• Recognized as A World’s Most Admired Company by Fortune in 2015
• One of the World’s Largest Energy and Construction Firms
Building a Better World
Organized to Help a Diverse Set of Clients

- Government
- Commercial
- NGO/Nonprofits
- Hybrid/Public Private Partnerships

AECOM Management Services

- Global Field Services (GFS)
- Intelligence Community Services (ICS)
- Mission Readiness (MRG)
- Nuclear & Environment (N&E)
- Systems Engineering & Information Solutions (SEIS)
Our “D4” Credentials — Decommissioning, Decontamination, Dismantling and Demolition
Some Examples of Site Projects

Savannah River Site SC
AFTER

BEFORE

River Corridor Project, Hanford, WA - 2014

2005

Dounreay, Scotland

East Tennessee Technology Park
Oak Ridge, TN - NOW

Before

7 April 2016

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Reactor Decommissioning — a Global Overview
Global Summary

- At the end of 2015, the world’s 441 reactors (382 GWe of nuclear capacity) accounted for 11% of world’s electricity
- Some 80% of existing nuclear capacity is in OECD countries. Of that more than three-quarters is over 25 years old
- By contrast, around half of the capacity in non-OECD countries (excluding Russia) is less than 15 years old
- Currently, 67 GW of nuclear capacity under construction, 21 reactors in OECD countries and 46 in non-OECD countries
- In 2015, WNA reports that 10 new reactors began commercial operations (+9497 MWe), while internationally eight reactors were shutdown for decommissioning (-4582 MWe)
- In total: 110 commercial reactors, 46 experimental or prototypes, and 250 research reactors as well as a number of fuel cycle facilities have been permanently shutdown. Some of these facilities have been fully dismantled.
- Over the next 20 years and beyond, the IAEA estimates that 150 GWs, or more than 200 nuclear plants, are expected to be retired, primed for or begin decommissioning
Global Summary

- Bulk of worldwide retirements are in the mature markets, i.e. oldest fleets first, reflecting the age profile of their fleets, particularly the European Union (led by France, Germany and UK), Russia, Japan and United States
- Rate of retirements picks up in the first half of the 2020s as reactors built in 1970s are taken off-line, and then again in the 2030s, particularly if life extensions in the U.S. are not re-extended for another 20 years
- Average rate of retirements is about 5 GWs per year, compared with new additions of 15 per year
- Main drivers for plant retirements include:
  1. Units that have achieved their expected economic lifetime, 75 %
  2. Units that are closed following an accident, 5%
  3. Units which are closed prematurely by political decision or due to regulatory reasons, 20%
Age Profile of Operating Reactors

- Global nuclear reactor fleet average age is 27 years
- OECD countries, reactor fleet is over 25 years
- Half of the capacity in Non-OECD countries is less than 15 years old
Age Profile of Operating Reactors

- 356 reactors over 20+ years
- 220 reactors over 30+ years
- 65 reactors over 40+ years
Around 150 GW of nuclear capacity is retired thru 2040, equivalent to 38% of the current installed capacity or 44% of the existing operating world fleet.
Overview

- Approximately 50% of the world's existing nuclear reactors are expected to be shutdown by 2030, creating a substantial market for the commercial nuclear reactor decommissioning industry in the years to come per GlobalData reports.
Decommissioning — USA

– Four U.S. Nuclear Power Stations with a total of 5 reactors (Crystal River 3, San Onofre 2&3, Vermont Yankee and Kewaunee) declared a permanent cessation of operations (4386 MWe) over the past couple of years

– U.S. nuclear fleet is the oldest in the world and averages 33 years

– 75 U.S. reactors have a 20 year life extension (to 60 years) and discussions are underway with the USNRC to extend licenses another 20 years to a total operating life of 80 years
Recent news reports indicate that first candidates for a second 20-year extension to 80 years are Dominion Resources’ Surry Plant in Virginia, Exelon’s Peach Bottom Plant in Pennsylvania and Duke Energy’s Oconee Plant in South Carolina.
Projected U.S. Nuclear Plant Capacity

Without additional new builds beyond those currently underway, total U.S. installed capacity begins to decline starting in 2027.
Decommissioning — Europe

- Germany shut down 8 units in 2011 and a 9th (Grafenrheinfeld) was shut down in 2015 – total (8942 MWe). Remaining 8 units will be shutdown by Dec 2022

- All the UK’s first generation Magnox units are now shutdown (4450 MWe) and in various stages of decommissioning

- France has a total of 13 power reactors to be decommissioned (4210 MWe)

- In addition to Germany, France and the UK, reactors in Bulgaria, Sweden, Slovakia and Spain have been shutdown and are being or will be decommissioned (5052 MWe)

- This is a total of 22654 MWe being decommissioned
EU nuclear fleet has a current average age of 30 years, almost half is expected to be retired by 2040.
Decommissioning — Asia

– So far, Japan has declared that 8 reactors will be decommissioned (excluding those at Fukushima Dai-ichi)
  • Hamaoka 1 & 2, Genkai 1, Mihama 1 & 2, Shimane 1, Tsuruga 1, and, most recently, Ikata 1 (2627 MWe in total)

– South Korea has announced that its first reactor (Kori 1) will be shutdown and decommissioned (556 MWe)

– Taiwan – if ChinShan 1 & 2 do not get their life extensions approved then they will shut down in 2018 and 2019 (1208 MWe)
Decommissioning Costs — U.S. Example

Based on U.S. data, decommissioning cost estimates are in the range of $750M to $1 billion per 1000MW plant.

Decommissioning options include:
- Immediate dismantling (prompt removal and processing of all radioactive material)
- Deferred dismantling or “SAFSTOR” (make safe and allow radioactive decay to occur before starting the dismantling process)

Figure 8: Decommissioning a nuclear power plant takes many years and costs vary widely. The highest costs will be incurred during the initial shutdown and final decommissioning and demolition. Any intervening period of standing by will be less expensive. These factors may influence decisions on how rapidly decommissioning will take place. Source United States Department of Energy (2010)
Summary

– Decommissioning has started now but from the mid-2020s will become an increasingly important segment of the nuclear energy industry.
– Many existing nuclear plants are approaching “mid-life” and future nuclear plant retirements are “around-the-corner” – decommissioning activity will therefore continue to grow through the 2030s.
– Total Spend on reactor decommissioning could exceed $200B over next three decades.
– Nuclear plant decommissioning costs vary significantly from country to country and depend on a range of factors, including:
  – Domestic economic/political/regulatory conditions.
  – Utilities’ financial strategies (including D&D funding options).
  – Availability of waste disposition options.
Thank you.
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### Table 11.2 Cumulative global investment and associated costs in nuclear power in the New Policies Scenario, 2014-2040 ($2013 billion)

<table>
<thead>
<tr>
<th></th>
<th>Investment in nuclear plants*</th>
<th>Associated costs</th>
<th>Total capacity additions (GW)</th>
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<td>Fuel cycle</td>
<td>Decommissioning</td>
<td>Total</td>
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<td>China</td>
<td>345</td>
<td>191</td>
<td>-</td>
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<tr>
<td>European Union</td>
<td>301</td>
<td>220</td>
<td>51</td>
</tr>
<tr>
<td>United States</td>
<td>247</td>
<td>236</td>
<td>15</td>
</tr>
<tr>
<td>Korea</td>
<td>103</td>
<td>78</td>
<td>1</td>
</tr>
<tr>
<td>India</td>
<td>96</td>
<td>37</td>
<td>1</td>
</tr>
<tr>
<td>Japan</td>
<td>37</td>
<td>54</td>
<td>10</td>
</tr>
<tr>
<td>Rest of world</td>
<td>406</td>
<td>161</td>
<td>27</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1 533</strong></td>
<td><strong>977</strong></td>
<td><strong>104</strong></td>
</tr>
</tbody>
</table>

*Investment in new plants and for uprates and refurbishments for life extensions at existing ones.*
## Investor-Owned Decommissioning per Plant Cost Estimates

### Investor-Owned Utilities

<table>
<thead>
<tr>
<th>Company</th>
<th>Lic Exp [Aug Yr]</th>
<th>MW Nuclear Capacity</th>
<th>Decommissioning Cost Estimate ($mm)</th>
<th>Front Balance ($mm)</th>
<th>PPA Foma Feed ($mm)</th>
<th>Annual Cost ($mm)</th>
<th>Current Amort</th>
<th>PPA Foma Amor</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>Ameren Corporation</td>
<td>2024</td>
<td>1,190</td>
<td>$754, $634</td>
<td>$850, $494</td>
<td>$456, $7</td>
<td>$41</td>
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<td>American Electric Power Company</td>
<td>2034-2037</td>
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<td>$1,375, $665</td>
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<td>$281, $10</td>
<td>$13</td>
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<td>Constellation Energy Nuclear Group</td>
<td>2029-2046</td>
<td>3,853</td>
<td>$3,677, $964</td>
<td>$3,677, $1,570</td>
<td>$1,070, $0</td>
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<td>Dominion Resources</td>
<td>2032-2045</td>
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<td>DTE Energy Company</td>
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<td>El Paso Electric Company</td>
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<td>$31, $612</td>
<td>$495, $214</td>
<td>$282, $5</td>
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<td>Energy Future Holdings Corporation</td>
<td>2030-2033</td>
<td>2,406</td>
<td>$1,319, $548</td>
<td>$1,920, $791</td>
<td>$1,129, $16</td>
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<td>Energy Corporation</td>
<td>2013-2038</td>
<td>12,233</td>
<td>$5,109, $517</td>
<td>$6,562, $4,419</td>
<td>$2,043, $39</td>
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<td>Exelon Corporation</td>
<td>2022-2040</td>
<td>11,122</td>
<td>$1,153, $675</td>
<td>$13,663, $8,071</td>
<td>$5,592, $24</td>
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<td>FirstEnergy Corporation</td>
<td>2017-2047</td>
<td>4,967</td>
<td>$3,265, $717</td>
<td>$3,748, $2,209</td>
<td>$1,539, $5</td>
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<td>Great Plains Energy</td>
<td>2043</td>
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<td>$296, $643</td>
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<td>$251, $3</td>
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<td>Green Mountain Power Corporation</td>
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<td>211</td>
<td>$11, $524</td>
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<td>$8, $0</td>
<td>$0</td>
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<td>MidAmerican Energy Company</td>
<td>2032</td>
<td>444</td>
<td>$329, $740</td>
<td>$354, $394</td>
<td>$40, $2</td>
<td>$2</td>
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<td>NextEra Energy</td>
<td>2030-2043</td>
<td>5,552</td>
<td>$4,500, $811</td>
<td>$4,500, $4,706</td>
<td>$208, $0</td>
<td>$10</td>
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<td>NRG Energy</td>
<td>2027-2028</td>
<td>1,126</td>
<td>$654, $492</td>
<td>$999, $551</td>
<td>$348, $5</td>
<td>$25</td>
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<td>Pacific Gas and Electric Company</td>
<td>2024-2025</td>
<td>2,303</td>
<td>$3,090, $1,559</td>
<td>$3,590, $2,666</td>
<td>$225, $23</td>
<td>$8</td>
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<tr>
<td>Pinnacle West Capital Corporation</td>
<td>2015-2047</td>
<td>1,146</td>
<td>$701, $612</td>
<td>$115, $642</td>
<td>$273, $17</td>
<td>$8</td>
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<tr>
<td>PPL Corporation</td>
<td>2042-2044</td>
<td>2,268</td>
<td>$1,245, $549</td>
<td>$1,810, $564</td>
<td>$446, $0</td>
<td>$33</td>
<td></td>
<td></td>
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<tr>
<td>Public Service Company of New Mexico</td>
<td>2014-2047</td>
<td>402</td>
<td>$246, $611</td>
<td>$321, $223</td>
<td>$98, $5</td>
<td>$3</td>
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<tr>
<td>Public Service Enterprise Group</td>
<td>2033-2046</td>
<td>3,622</td>
<td>$2,180, $602</td>
<td>$2,890, $1,701</td>
<td>$1,189, $0</td>
<td>$46</td>
<td></td>
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<tr>
<td>San Diego Gas and Electric Company</td>
<td>2013</td>
<td>430</td>
<td>$967, $2,015</td>
<td>$967, $607</td>
<td>$540, $3</td>
<td>$8</td>
<td></td>
<td></td>
<td>N.A.</td>
</tr>
<tr>
<td>SCANA Corporation</td>
<td>2042</td>
<td>644</td>
<td>$697, $1,082</td>
<td>$697, $101</td>
<td>$596, $3</td>
<td>$12</td>
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<tr>
<td>Southern California Edison</td>
<td>2015-2047</td>
<td>2,304</td>
<td>$3,756, $1,630</td>
<td>$3,756, $4,237</td>
<td>$801, $23</td>
<td>$53</td>
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<td>Southern Company</td>
<td>2004-2049</td>
<td>3,667</td>
<td>$2,817, $768</td>
<td>$2,926, $1,460</td>
<td>$1,446, $3</td>
<td>$54</td>
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<td>Western Energy</td>
<td>2019</td>
<td>545</td>
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<td>$259, $3</td>
<td>$8</td>
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<td>Xcel Energy</td>
<td>2020-2034</td>
<td>1,594</td>
<td>$2,684, $1,809</td>
<td>$2,804, $1,622</td>
<td>$257, $2</td>
<td>$56</td>
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</table>

Investor-Owned Utilities Totals: 83,391 66,588 738 74,294 50,475 23,819 315 1,914

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See Appendix page 14 for Notes

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*Callan | Knowledge. Experience. Integrity.*
Locations of Power Reactor Sites Undergoing Decommissioning

The NRC’s Office of Nuclear Material Safety and Safeguards (NMSS) has project management responsibilities for 19 power reactors undergoing decommissioning.
# State of Play — Nuclear Energy Worldwide

## Power Reactor Sites Undergoing Decommissioning

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal River – Unit 3</td>
<td>Crystal River, FL</td>
</tr>
<tr>
<td>Dresden – Unit 1</td>
<td>Dresden, IL</td>
</tr>
<tr>
<td>Fermi – Unit 1</td>
<td>Newport, MI</td>
</tr>
<tr>
<td>Humboldt Bay</td>
<td>Eureka, CA</td>
</tr>
<tr>
<td>Indian Point – Unit 1</td>
<td>Buchanan, NY</td>
</tr>
<tr>
<td>Kewaunee</td>
<td>Kewaunee, WI</td>
</tr>
<tr>
<td>LaCrosse Boiling Water Reactor</td>
<td>Genoa, WI</td>
</tr>
<tr>
<td>Millstone – Unit 1</td>
<td>Waterford, CT</td>
</tr>
<tr>
<td>Nuclear Ship Savannah</td>
<td>Baltimore, MD</td>
</tr>
<tr>
<td>Peach Bottom – Unit 1</td>
<td>Delta, PA</td>
</tr>
<tr>
<td>San Onofre – Unit 1</td>
<td>San Clemente, CA</td>
</tr>
<tr>
<td>San Onofre – Units 2 &amp; 3</td>
<td>San Clemente, CA</td>
</tr>
<tr>
<td>Three Mile Island – Unit 2</td>
<td>Middletown, PA</td>
</tr>
<tr>
<td>General Electric Co. – ESADA Vallecitos Experimental Superheat Reactor (EVESR)</td>
<td>Sunol, CA</td>
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<tr>
<td>General Electric Co. – Vallecitos Boiling Water Reactor (VBWR)</td>
<td>Sunol, CA</td>
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<tr>
<td>Vermont Yankee</td>
<td>Vernon, VT</td>
</tr>
<tr>
<td>Zion – Units 1 &amp; 2</td>
<td>Zion, IL</td>
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</tbody>
</table>
U.S. Nuclear Plant Age Distribution

Figure 24. U.S. Commercial Nuclear Power Reactors—Years of Operation by the End of 2014

- 33 reactors (10-19 years)
- 35 reactors (20-29 years)
- 31 reactors (30-39 years and > 40 years)

Note: Ages have been rounded up to the end of the year. These numbers include Vermont Yankee, which is scheduled to cease operations at the end of 2014.
Expected U.S. Reactor Retirements

Figure 25 U.S. Commercial Nuclear Power Reactor Operating Licenses—Expiration by Year

License Expiration

2013–2019  3
2020–2023  4
2024–2030  26
2031–2049  67

Indicates Indian Point 2, which entered timely renewal on Sept. 29, 2013.
Note: These numbers include Vermont Yankee, which is scheduled to cease operations at the end of 2014.
# U.S. New Capacity Required to Maintain Relative Fuel Share

## Figure 2

**New Nuclear Generating Capacity Needed If All Reactors Retire After 60 Years of Operation**

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Electric Generation (bkWh)</th>
<th>Nuclear Capacity (GW)</th>
<th>Nuclear Generation (bkWh)</th>
<th>Nuclear Fuel Share</th>
<th>New Generation Needed to Meet Fuel Share (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20%</td>
</tr>
<tr>
<td>2025</td>
<td>4,622.3</td>
<td>104.0</td>
<td>820.0</td>
<td>17.7%</td>
<td>13.2</td>
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<tr>
<td>2030</td>
<td>4,815.1</td>
<td>100.0</td>
<td>788.0</td>
<td>16.4%</td>
<td>22.2</td>
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<tr>
<td>2035</td>
<td>5,004.3</td>
<td>72.4</td>
<td>570.4</td>
<td>11.4%</td>
<td>54.6</td>
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<tr>
<td>2040</td>
<td>5,219.7</td>
<td>57.5</td>
<td>453.2</td>
<td>8.7%</td>
<td>74.9</td>
</tr>
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</table>

*Data Source: Energy Information Administration, Annual Energy Outlook 2014*
### Order of Magnitude Decommissioning Cost Estimates thru 2040

<table>
<thead>
<tr>
<th>Decommission Market Segment</th>
<th>Estimate of Decommissioning Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.</td>
<td>$30 billion</td>
</tr>
<tr>
<td>France</td>
<td>$25 billion</td>
</tr>
<tr>
<td>Russia</td>
<td>$15 billion</td>
</tr>
<tr>
<td>U.K.</td>
<td>$20 billion</td>
</tr>
<tr>
<td>Germany</td>
<td>$25 billion</td>
</tr>
<tr>
<td>Japan</td>
<td>$30-50 billion (exc Fukushima Daiichi)</td>
</tr>
<tr>
<td>Total</td>
<td>$155-175 billion</td>
</tr>
</tbody>
</table>

- Decommissioning market size could be over $150 billion thru 2040
- Decommissioning costs are in the order of 10 percent of the investment in new nuclear capacity over the period