An Overview of Spent Fuel Storage in the US

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Carlyn Greene
Executive Director, Back-end Publications
The Ux Consulting Company, LLC
Roswell, Georgia

www.uxc.com
UxC – The Ux Consulting Company

- Provides nuclear fuel consulting and market information services to suppliers, utilities, investors, and government agencies internationally
  - Founded in March 1994
  - 15 professionals in company, plus consultant base
  - Home office is in Atlanta, GA

- Three major lines of business
  - Nuclear fuel cycle consulting
  - Publishing industry market reports
  - Data services
Consulting Services

- **Market Analyses** – Impacts of various market developments on supply, demand, and price
- **Strategic Planning** – Positioning clients to succeed in changing business climate
- **Procurement Strategies** – Informing utilities’ decisions on market timing, pricing, and inventories
- **Utility Procurement Training Seminars** – Basic and advanced seminars for utility fuel managers
- **Policy Issues** – Assessing impact of government policies on clients’ businesses and general market
- **Litigation and Arbitration Support** – Providing expert market and economic advice in legal proceedings
UxC Covers All Fuel Cycle Segments

Uranium Exploration & Development

Mining of Uranium Ore

Milling of Ore to U₃O₈ Concentrates

Conversion to UF₆

Uranium Enrichment (SWU)

Fuel Fabrication

Nuclear Reactor

Spent Fuel Storage

Waste Disposal

U & Pu Recycle

Reprocessing

INMM Spent Fuel Management Seminar January 2018 - 4
California PUC Approves Most of PG&E’s Joint Proposal to Close Diablo Canyon

On January 11, the California Public Utilities Commission (CPUC) approved Pacific Gas & Electric Company’s (PG&E) request to close the Diablo Canyon Nuclear Power Plant by 2021, but did not approve all of the elements of the company’s proposal. The CPUC agreed to allow the company to initially operate the plant at its current levels, but also required that the company develop a plan to reduce its operating costs and improve its financial stability.

The Diablo Canyon plant is located in central San Luis Obispo County, and consists of two units that have been operating since 1987 (Unit 1) and 1989 (Unit 2), with a combined generation capacity of 2,400 megawatts. The two units are currently licensed by the Nuclear Regulatory Commission (NRC) to operate until 2022 and 2023, respectively.

In June 2018, PG&E filed an application with the NRC to extend the operating licenses for Diablo Canyon 1 and 2. On June 21, 2018, however, PG&E announced that it would not pursue renewal of the Diablo Canyon operating licenses because they expire on May 2023.

The CPUC decided to allow PG&E to operate Diablo Canyon 1 and 2 until May 2023, provided that the company demonstrates the ability to reduce its operating costs and improve its financial stability. The CPUC also required PG&E to develop a plan to reduce its operating costs and improve its financial stability.

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Global Spent Fuel Storage Overview

- With no permanent disposal facility for spent nuclear fuel operational anywhere in the world, more than 50 countries have spent fuel in storage awaiting reprocessing or disposal, with 80% of the world’s inventory of spent fuel in storage located in the US and Western Europe.

- About 10,000 MT of spent fuel is discharged per year globally.

- Up to 3,000 MT of that is intended to be reprocessed, so annual spent fuel accumulation totals about 7,000 MT.

- UxC projects this total to increase, with as much as 15,000 MT discharged in 2030.

- WNA currently reports that about 250,000 MT are in storage, mostly at reactor sites – some at interim storage facilities or stored at reprocessing facilities. About two-thirds of this is in spent fuel pools, but the amount placed into dry storage each year is increasing.

- According to the IAEA, about 370,000 MT in the form of spent fuel have been discharged to date; about 120,000 MT have been reprocessed, with the remaining 250,000 MT in storage, which is in line with the WNA estimate.
Global Spent Fuel Storage Overview

► In a few countries, such as Sweden and Switzerland, consolidated storage facilities, both wet and dry, are operational. Spain is planning a consolidated storage facility; Ukraine is currently building one; EDF in France has recently taken steps to build one, and action is being taken in the US to build up to two privately-run consolidated storage facilities and one federally-operated facility.

► In UxC’s *Nuclear Power Outlook* and *Requirements Model* reports, we estimate nuclear reactor requirements and spent fuel discharges over time. As of mid-2017, we estimated that the world’s nuclear power programs will discharge approximately 560,000 MT of spent fuel through 2030. Less than 30% of that will be reprocessed and the rest placed into storage, or possibly into a repository if one is operational by then.

► In UxC’s *Nuclear Industry Value Chain* report, we estimated the overall dry cask storage market size to be about $12.4 billion in 2015 US$ from 2015 through 2030.
Not much changed in 2017 in terms of policy.

- Commercial spent fuel continues to be safely stored at reactor sites around the country. The NRC continues to regulate its storage, and the federal government continues to shell out taxpayer money to reimburse utilities for the cost to store it.

- Studies are ongoing that will confirm the safety of storing spent fuel in dry storage for up to 300 years.

- An EPRI-led team is continuing to study the performance of high burnup fuel that has been in storage for very long periods of time. In November, a TN-32B cask was loaded with high burnup fuel from North Anna and placed on the North Anna storage pad as part of that study.
…But the focus has changed.

- With the change in administration last year, the focus shifted from consent-based siting of a repository that is anything but Yucca Mountain to restarting the Yucca Mountain licensing proceeding.
- President Trump included $120 million to advance the nuclear waste management program by restarting the proceedings and establishing an interim storage program.
- Since both the executive and legislative branches of government (at least the House) support Yucca Mountain, 2017 began with much optimism that progress towards nuclear waste disposal would be made (i.e. implementing legislation and appropriations), but little has changed compared to prior years except for the budget request.
- DOE has abandoned two Obama/Moniz-era ideas – pursuing a separate repository for defense waste, and deep borehole disposal of some types of waste.

As has been the case the last several years, in 2017, legislation was introduced in Congress that would give DOE clear authority to store spent fuel even without progress on a repository, but that legislation never made it out of committee. Hearings were held, and optimism is high (again) that a bill will clear the House maybe as early as this month.
<table>
<thead>
<tr>
<th>Date</th>
<th>Bill number</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 11</td>
<td>H.R. 433</td>
<td>The Sensible Nuclear Waste Disposition Act</td>
</tr>
<tr>
<td>January 11</td>
<td>S. 95</td>
<td>The Nuclear Waste Informed Consent Act</td>
</tr>
<tr>
<td>January 12</td>
<td>H.R. 474</td>
<td>The Interim Consolidated Storage Act</td>
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</table>
| May 25    | S. 1265     | Dry Cask Storage Act
Earlier versions introduced May 23, 2014 (S.2325) and April 15, 2015 (S.945) |
| June 26   | H.R. 3053   | **Nuclear Waste Policy Amendments Act**
Cleared the House E&C Committee 49-4; a hearing was held; committee issued a report on the bill October 19. |
| October 2  | S. 1903     | Sensible, Timely Relief for America’s Nuclear Districts’ Economic Development Act (STRANDED) |
| October 3  | H.R. 3929   | Stranded Nuclear Waste Accountability Act                  |
| October 5  | H.R. 3970   | Companion bill to the Senate STRANDED bill                 |
| November 16 | H.R. 4442  | Removing Nuclear Waste From Our Communities Act            |
Some Industry and Government Activities in 2017


  - Report summarizes the studies of rail and truck transport accidents involving fires, relative to regulatory requirements for shipment of commercial spent nuclear fuel. NUREG/CR-7209.

  - Report notes that in nearly 21 billion miles of travel in the US between 1975 and 2005, 1,700 reported incidents involved the release of hazardous materials. None of the incidents reviewed involved the release of any radioactive material.
Government and Industry Activities in 2017 (continued)

- Work to ensure cask integrity over the long term.

  - NRC issued draft MAPS Report in October for public comment.
    - A guidance document that provides the staff’s technical position about aging mechanisms that could affect dry storage systems during a renewal period.

  - NRC issued draft SRP in November for spent fuel dry storage systems and facilities.
    - A guidance document for the staff to use in reviewing SARs, CoCs, and site-specific ISFSI renewals.

  - EPRI and industry developing techniques to detect a “part-wall” crack in canisters, and vendors are working to improve canister inspection technology.

  - Work continued to improve the efficiency of the regulatory framework for dry storage (graded approach), and the pilot CoC amendment, NUHOMS Amendment 16, was submitted in June. Industry hopes the NRC will endorse the guidance in late 2019.
Consolidated Storage in the US

<table>
<thead>
<tr>
<th>One application for a private consolidated storage facility was submitted to the NRC in 2016.</th>
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<tbody>
<tr>
<td>Waste Control Specialists (WCS) submitted an application to build a Consolidated Interim Storage Facility (CISF) at the site of its LLW disposal facility in Andrews County, Texas.</td>
</tr>
<tr>
<td>- The application for a site-specific Part 72 license references TN Americas and NAC storage technology.</td>
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<tr>
<td>- Has broad local and state consent.</td>
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<td>- The facility would be built in up to 8 phases with an eventual capacity of up to 40,000 MT.</td>
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<tr>
<td>- The NRC accepted the application for review in January 2017; in April, WCS requested that the NRC suspend its review of this application.</td>
</tr>
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</table>
Holtec International submitted an application in March 2017

- The facility, named the HI-STORE, would be located near Carlsbad, New Mexico.
  - Holtec has partnered with the Eddy-Lea Energy Alliance (ELEA) for this facility.
  - Holtec’s HI-STORM UMAX (underground, maximum capacity) storage system will be the only system used.
  - Has strong local and state consent.
  - Holtec plans to build its CISF in up to 20 phases with a potential total capacity of 100,000 MT.
  - Holtec submitted the last set of RSI responses in December; the NRC staff is finalizing its acceptance review of the application.

- DOE, while recognizing the role that the private entities could play in consolidated storage, still plans to build a federal CISF.
  - Without authorization from Congress, however, no particular site can be studied, so DOE continues with generic studies of possible CISF designs.
Dry Storage in the US

► Every US nuclear reactor site except for TMI-1, Shearon Harris, and Wolf Creek either has dry storage implemented or has near-term plans to implement dry storage.

► Currently, 79 ISFSIs are licensed in the US.
  • This number includes the five sites that have both a general and a site-specific ISFSI license as two ISFSIs, and includes the PFS facility (which has a license but never operated), the TMI-2 facility in Idaho, and the DOE Idaho spent fuel facility.
  • Three new ISFSIs started operating in 2016 at V.C. Summer, Watts Bar, and Clinton.
  • One new ISFSI began operations in 2017 at Crystal River 3. Loading operations began in June and by mid-January, 2018, all 39 NUHOMS 32PTH1 DSCs had been placed into service.

► South Texas Project is planning to have an ISFSI in operation in 2019.
15 sites operate an ISFSI with a site-specific license and 64 sites operate with a general license. The site-specific sites include:

- The wet storage ISFSI at the GE-Morris facility in Illinois.
- The TMI-2 ISFSI at INL.
- DOE spent fuel stored at INL.
- The PFS facility with an NRC license (but it never operated).

To date, 7 site-specific ISFSI licenses have been renewed – most recently Prairie Island’s in December 2015.

- In May 2016, Dominion submitted a license renewal application for the North Anna ISFSI.
- In March 2017, DOE submitted a renewal application for the TMI-2 ISFSI, and Portland GE submitted a renewal application for Trojan’s ISFSI.
- By the end of March 2018, PG&E and SMUD plan to submit renewal applications for Humboldt Bay and Rancho Seco.
Certificates of Compliance are also being renewed.

- NUHOMS – Renewed CoC took effect on December 11, 2017.
- Other systems will be up for renewal before 2020.
  - The NRC is expecting to receive renewal applications for the HI-STORM 100, the TN-32, TN-68, NAC-MPC, and NAC-UMS.
### ISFSIs with Site-Specific Licenses

<table>
<thead>
<tr>
<th>Licensee</th>
<th>Site</th>
<th>License</th>
<th>Initial License Expiration Date</th>
<th>Renewed License Expiration Date</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominion</td>
<td>Surry</td>
<td>SNM-2501</td>
<td>2006</td>
<td>2046</td>
<td>License renewed in 2005 with exemption for an additional 20 years</td>
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<tr>
<td>Progress Energy</td>
<td>H.B. Robinson</td>
<td>SNM-2502</td>
<td>2006</td>
<td>2046</td>
<td>License renewed in 2005 with exemption for additional 20 years</td>
</tr>
<tr>
<td>Duke</td>
<td>Oconee</td>
<td>SNM-2503</td>
<td>2010</td>
<td>2050</td>
<td>License renewed in 2009 with exemption for an additional 20 years</td>
</tr>
<tr>
<td>DOE</td>
<td>Ft. St. Vrain</td>
<td>SNM-2504</td>
<td>2011</td>
<td>2031</td>
<td>License renewed in 2011 for an additional 20 years</td>
</tr>
<tr>
<td>Constellation</td>
<td>Calvert Cliffs</td>
<td>SNM-2505</td>
<td>2012</td>
<td>2052</td>
<td>Renewed October 23, 2014 for a 40-year period</td>
</tr>
<tr>
<td>Xcel Energy</td>
<td>Prairie Island</td>
<td>SNM-2506</td>
<td>2013</td>
<td>2053</td>
<td>Renewed December 9, 2015 for a 40-year period</td>
</tr>
<tr>
<td>Dominion</td>
<td>North Anna</td>
<td>SNM-2507</td>
<td>2018</td>
<td>N/A</td>
<td>Renewal application submitted May 25, 2016</td>
</tr>
<tr>
<td>DOE</td>
<td>TMI-2</td>
<td>SNM-2508</td>
<td>2019</td>
<td>N/A</td>
<td>Renewal submitted on March 6, 2017</td>
</tr>
<tr>
<td>Portland GE</td>
<td>Trojan</td>
<td>SNM-2509</td>
<td>2019</td>
<td>N/A</td>
<td>Renewal submitted on March 23, 2017</td>
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<tr>
<td>SMUD</td>
<td>Rancho Seco</td>
<td>SNM-2510</td>
<td>2020</td>
<td>N/A</td>
<td>Renewal to be submitted by March 28, 2018</td>
</tr>
<tr>
<td>GE</td>
<td>GE-Morris (wet storage)</td>
<td>SNM-2500</td>
<td>2022</td>
<td>2022</td>
<td>License renewed in 2004 for 20 years; was the first ISFSI license renewed</td>
</tr>
<tr>
<td>PG&amp;E</td>
<td>Diablo Canyon</td>
<td>SNM-2511</td>
<td>2024</td>
<td>N/A</td>
<td>Renewal not yet submitted</td>
</tr>
<tr>
<td>DOE</td>
<td>Idaho Spent Fuel Facility</td>
<td>SNM-2512</td>
<td>2024</td>
<td>N/A</td>
<td>Renewal not yet submitted</td>
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<tr>
<td>PG&amp;E</td>
<td>Humboldt Bay</td>
<td>SNM-2514</td>
<td>2025</td>
<td>N/A</td>
<td>Renewal to be submitted by March 2018</td>
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</table>
# Growth of Commercial Dry Storage

<table>
<thead>
<tr>
<th>End of Year</th>
<th>Assemblies</th>
<th>Casks</th>
<th># Placed in Service</th>
<th># of ISFSIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>41,856</td>
<td>1,111</td>
<td>152</td>
<td>54</td>
</tr>
<tr>
<td>2009</td>
<td>47,455</td>
<td>1,240</td>
<td>129</td>
<td>54</td>
</tr>
<tr>
<td>2010</td>
<td>54,046</td>
<td>1,387</td>
<td>147</td>
<td>63</td>
</tr>
<tr>
<td>2011</td>
<td>60,304</td>
<td>1,542</td>
<td>155</td>
<td>63</td>
</tr>
<tr>
<td>2012</td>
<td>67,831</td>
<td>1,710</td>
<td>168</td>
<td>69</td>
</tr>
<tr>
<td>2013</td>
<td>76,097</td>
<td>1,892</td>
<td>182</td>
<td>70</td>
</tr>
<tr>
<td>2014</td>
<td>85,166</td>
<td>2,087</td>
<td>195</td>
<td>72</td>
</tr>
<tr>
<td>2015</td>
<td>93,426</td>
<td>2,277</td>
<td>190</td>
<td>75</td>
</tr>
<tr>
<td>2016</td>
<td>102,416</td>
<td>2,471</td>
<td>194</td>
<td>78</td>
</tr>
<tr>
<td>2017</td>
<td>113,797</td>
<td>2,720</td>
<td>249</td>
<td>79</td>
</tr>
</tbody>
</table>
Shutdown Sites

Transferring the spent fuel from the pool to dry storage is an important decommissioning milestone.

- Since 2013, a total of 14 reactors have shut down prematurely or the owners have announced plans to close between 2018 and 2025. Six have closed since 2013, and eight more are scheduled to close between 2019 and 2025.

- Out of a total of 2,720 casks in service in the US, 463 of these are at permanently shutdown sites. Some of these sites, such as Big Rock Point, the Yankee sites, and others, have nothing left of the former reactor site except the ISFSI.

- In 2017, two sites completed the transfer of all spent fuel out of the pool into dry storage, another site made progress towards that goal, and one site will begin this work later this month:
  - **Kewaunee** – in June transferred the last of the spent fuel from the pool into dry storage when the last MAGNASTOR system was moved to the pad; 888 assemblies were transferred into 24 systems in 23 weeks; loading duration averaged 3.2 days per cask.
  - **Crystal River 3** – just a couple of weeks ago completed transferring all 1,232 spent fuel assemblies from the pool into NUHOMS 32PTH1 systems. This campaign began on June 18, 2017.
Shutdown Sites (continued)

- Shutdown sites transferring spent fuel into dry storage (continued):
  - **Vermont Yankee** – Had 13 HI-STORMs on the pad, then resumed cask loading operations in June 2017, and as of early January had completed loading 22 more, so a total of 35 systems are storing 2,380 assemblies (as of early January). VY plans to load a total of 24 systems in 2018, which will complete the cask loadings at VY.
  
  - **Southern California Edison** – Scheduled to begin loading the rest of SONGS spent fuel into HI-STORM UMAX systems later this month; currently has 51 of TN Americas’ Standardized Advanced NUHOMS systems in use. The site plans to load 73 UMAX systems this year (Unit 2 fuel will require 36 canisters and Unit 3 fuel will require 37 canisters; 4-10 canisters will be needed to store GTCC waste from Units 2 and 3).

- By 2022:
  
  - **Omaha Public Power District** – Expected to make a decision early this year on which company will place the remaining 944 assemblies in the Fort Calhoun pool into dry storage. Currently the site has 10 NUHOMS 32 PT systems in use, storing 320 assemblies. Depending on the design chosen, 26-30 casks are expected to be purchased.
Spent Fuel Storage Key Players - US

- **TN Americas is AREVA’s dry storage and spent fuel transport company**
  - Currently markets the modular NUHOMS dry cask system, which is in use at 28 US sites storing ~35,360 assemblies in more than 960 systems.
  - Its bare fuel metal cask system is in use at 5 sites with 187 systems in service.
  - Has a total of over 44,850 assemblies stored in ~1,150 systems in the US.
  - In 2017, 4,588 assemblies were placed into 111 TN systems.

- **Holtec International**
  - Best known for its HI-STORM cask technology.
  - In use at 34 US sites, storing more than 52,500 assemblies in over 1,025 casks.
  - Newer variations of the HI-STORM 100 include the HI-STORM FW and the HI-STORM UMAX.
  - In 2017, 5,312 assemblies were placed into 92 Holtec casks.
Spent Fuel Storage Key Players - US

► NAC International

- Specializes in nuclear materials transport, spent fuel storage and transport technologies, nuclear fuel cycle consulting, and fuel cycle information services.

- NAC systems are in use at 12 US sites, storing over 12,500 assemblies in more than 450 casks.

- In 2017, 1,481 assemblies were placed into 46 NAC casks.

► EnergySolutions

- Renewal of its VSC-24 system was finalized in early 2017.

- ES has 66 cask systems storing 1,833 assemblies in use at 4 US plants.

- ES operates a LLW facility in Utah and Tennessee.

- ES also manages customized projects for utility customers, such as the Zion and LACBWR decommissioning projects.
Current Status of Dry Storage

Number of Assemblies in dry storage at the end of 2017

Dual-Purpose concrete casks in use

Total casks in use

INMM Spent Fuel Management Seminar January 2018
Market Share – PWR Fuel

Dual-purpose concrete systems deployed

PWR assemblies in dual-purpose concrete systems

INMM Spent Fuel Management Seminar January 2018 - 26
Market Share at Shutdown Sites

- TN Americas: 35%
- BFS/ES: 2%
- Holtec: 16%
- NAC: 47%

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Final Thoughts

► The dry storage market in the US will continue to see steady growth for the next several decades.

- With premature reactor shutdowns, the number of casks required in the near term will increase as the full pool, including the reactor core, is offloaded to dry storage, but in the longer term, fewer casks will be required.

► Close to 250 casks were deployed in 2017, and at least that many are expected to be placed into service in 2018 at commercial reactor sites in the US.

► The global dry storage market also will continue to grow as a result of:

- Decommissioning plants (Germany).
- Delays in repository programs.
- Delays in reprocessing plants in countries that are pursuing reprocessing.
Thank you

GOODBYE