Spent Fuel Dry Storage: Challenges and Lessons Learned From Recent Project Experience at Shutdown Nuclear Plants in the U.S.

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6/17/2015
Outline

1. Decommissioning status and trends
2. Decommissioning dry storage status & drivers
3. Decommissioning dry storage challenges
4. Recent decommissioning dry storage projects
5. Summary and Conclusion
Current nuclear plant status

- 99 Commercial reactors in operation (Compared to 104 in 2014)
- 5 Commercial reactors under construction (Vogtle [2 units], VC Summer [2 units], Watts Bar Unit 2)

Recent Shutdown Reactor Status:

<table>
<thead>
<tr>
<th>Plant</th>
<th>Rating</th>
<th>Shutdown Date</th>
<th>Owner</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal River</td>
<td>860 MWe</td>
<td>February 2013</td>
<td>Duke</td>
<td>Economics/Repairs</td>
</tr>
<tr>
<td>Kewaunee</td>
<td>566 MWe</td>
<td>May 2013</td>
<td>Dominion</td>
<td>Economics/Market</td>
</tr>
<tr>
<td>San Onofre 2&amp;3</td>
<td>2,160 MWe</td>
<td>June 2013</td>
<td>SCE</td>
<td>Economics/Repairs</td>
</tr>
<tr>
<td>Vermont Yankee</td>
<td>635 MWe</td>
<td>December 2014</td>
<td>Entergy</td>
<td>Economics</td>
</tr>
</tbody>
</table>

All five recently shutdown reactors plan to proceed with prompt defueling into dry storage followed by a period of safe preservation prior to dismantlement and decontamination (D&D).
U.S. Decommissioning Alternatives

- SAFSTOR (deferred dismantlement) - Facility is placed and maintained in a condition that allows the facility to be safely stored until subsequent decontamination and dismantling (up to 60 years).

- DECON - Facility is considered undergoing decontaminating and dismantling to levels that permit release for unrestricted use.

- ENTOMB - Radioactive structures are encased onsite with grout or concrete (provides structural protection and shielding). The facility is then maintained and monitored until the radioactivity decays to a level permitting restricted release of the property.

FACT: Of the 20 shutdown reactors with fuel onsite in the U.S., 9 are in SAFSTOR, 4 are in DECON, and 7 have completed DECON.
## U.S Decommissioning Dry Storage Status

<table>
<thead>
<tr>
<th>Reactor Name</th>
<th>Type</th>
<th>MWth</th>
<th>State</th>
<th>License Issued</th>
<th>Shutdown Date</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Rock Point</td>
<td>BWR</td>
<td>240</td>
<td>MI</td>
<td>5/1/1964</td>
<td>8/29/1997</td>
<td>DECON completed ISFSI on site</td>
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<tr>
<td>Fort St. Vrain</td>
<td>HTG</td>
<td>842</td>
<td>CO</td>
<td>12/21/1973</td>
<td>8/18/1989</td>
<td></td>
</tr>
<tr>
<td>Rancho Seco</td>
<td>PWR</td>
<td>2,772</td>
<td>CA</td>
<td>8/16/1974</td>
<td>6/7/1989</td>
<td></td>
</tr>
<tr>
<td>Yankee Rowe</td>
<td>PWR</td>
<td>600</td>
<td>MA</td>
<td>12/24/1963</td>
<td>10/1/1991</td>
<td></td>
</tr>
<tr>
<td>Humboldt Bay 3</td>
<td>BWR</td>
<td>200</td>
<td>CA</td>
<td>8/28/1962</td>
<td>7/2/1976</td>
<td>DECON in progress ISFSI on site</td>
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<tr>
<td>San Onofre 1(^{(a)})</td>
<td>PWR</td>
<td>1,347</td>
<td>CA</td>
<td>3/27/1967</td>
<td>11/30/1992</td>
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<td>Zion 1</td>
<td>PWR</td>
<td>3,250</td>
<td>IL</td>
<td>10/19/1973</td>
<td>2/21/1997</td>
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<tr>
<td>Zion 2</td>
<td>PWR</td>
<td>3,250</td>
<td>IL</td>
<td>11/14/1973</td>
<td>9/19/1996</td>
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<tr>
<td>LaCrosse</td>
<td>BWR</td>
<td>165</td>
<td>WI</td>
<td>7/3/1967</td>
<td>4/30/1987</td>
<td>SAFSTOR with ISFSI on site</td>
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<tr>
<td>Crystal River 3</td>
<td>PWR</td>
<td>2,609</td>
<td>FL</td>
<td>12/3/1976</td>
<td>2/20/2013</td>
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<td>Kewaunee</td>
<td>PWR</td>
<td>1,772</td>
<td>WI</td>
<td>12/21/1973</td>
<td>5/7/2013</td>
<td>SAFSTOR - ISFSI pending</td>
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<tr>
<td>San Onofre 2</td>
<td>PWR</td>
<td>3,438</td>
<td>CA</td>
<td>2/16/1982</td>
<td>6/7/2013</td>
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<tr>
<td>San Onofre 3</td>
<td>PWR</td>
<td>3,438</td>
<td>CA</td>
<td>11/15/1982</td>
<td>6/7/2013</td>
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<tr>
<td>Vermont Yankee</td>
<td>BWR</td>
<td>1,912</td>
<td>VT</td>
<td>3/21/1972</td>
<td>12/29/2014</td>
<td>SAFSTOR (other operating reactors)</td>
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<tr>
<td>Dresden 1</td>
<td>BWR</td>
<td>700</td>
<td>IL</td>
<td>9/28/1959</td>
<td>10/31/1978</td>
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<tr>
<td>Indian Point 1</td>
<td>PWR</td>
<td>615</td>
<td>NY</td>
<td>3/26/1962</td>
<td>10/31/1974</td>
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<td>Millstone 1</td>
<td>BWR</td>
<td>2,011</td>
<td>CT</td>
<td>10/31/1986</td>
<td>7/21/1998</td>
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</tr>
</tbody>
</table>
There are fourteen (14) shutdown sites (sites with no other operating reactors)

- Ten (10) sites have relocated all spent fuel into dry storage
  - Seven (7) completed DECON
  - Two (2) with DECON in process
  - One (1) in SAFSTOR
- Four (4) sites (recent shutdowns) planning to defuel within 5 years.

Note: Five (5) out of the ten (10) shutdown sites that have relocated all spent fuel into dry storage systems use NAC cask technology.
U.S. Decommissioning Recent Trends

- SAFSTOR with prompt transfer of SF into dry storage
  - Safety and robustness of dry storage (National Academy of Science study)
  - Heightened stakeholder interest in getting pool out of shutdown pools post 9/11 and post-Fukushima
  - Strong economic driver for removing fuel from pool
  - $10M-$30M annually in reduced operations and security staff

FACT: SAFSTOR with dry storage is viewed as having safety, security and economical advantages over SAFSTOR with wet storage
U.S. Decommissioning Recent Trends

- Dismantle & decommission when safe and economically viable
  - Adequate decommissioning funds for project, including risks
  - Decommissioning fund growth (time value of money vs. cost)
  - Adequate time for decay of radioactivity for worker safety and lower decommissioning costs

- Some communities/stakeholders pushing for prompt decommissioning

- Most stakeholders agree on accelerated movement of the fuel to dry storage regardless of the decommissioning approach.
U.S Decommissioning Dry Storage Drivers

- Safety - regulatory certification is a prerequisite
- Security (physical) - including some assurance of capability beyond design basis
- Schedule - prompt loading and completion of ALL fuel loading - even damaged fuel, reconstituted assemblies, lead test assemblies, high burnup fuel, “underburned” fuel, etc.
- Reasonable assurance of transportability
- Low financial risk (for plant owner)
Decommissioning Dry Storage: Zion Achievements/Lessons Learned

- Designed and licensed revisions to address site specific contents and operational requirements
  - Damaged fuel was canned
  - HBU fuel was canned (transport licensing expediency in consideration of specific contract requirements)
  - Underburned (1 cycle) fuel reactivity mitigated by loading with full length Rod Control Cluster Assemblies
  - Optimized loading plan for adhering to offsite boundary dose rate limits with new tighter site boundary (550 ft from ISFSI)
- Used three different fabricators (Hitachi Zosen, GEH, Peterson) to managed risk of delivery
- Largest U.S. single dry storage campaign of 61 spent fuel casks in less than 55 weeks
Kewaunee Dry Storage Project: Site Specific Requirements and Achievements

- Development of a 4-Zone cask loading pattern that permits the MAGNASTOR system to accept Kewaunee assemblies up to 1.8 kW from the last cycle (3-year cool time) with colder fuel (up to 0.8 kW) on the periphery to limit radiological dose
- Design and deployment of an integrated yoke/chain hoist system to address seismic requirements and optimize canister transfer operations
- Design and construction of an ISFSI facility that will accommodate MAGNASTOR casks to co-exist with horizontal systems already onsite
- Develop a cask loading sequences that address site boundary dose rate requirements upon complete defueling of the Kewaunee spent fuel pool
Dominion Kewaunee Power Station
Project Status

- MAGNASTOR CoC Amendment 5 published in the U.S. Federal Register
- TSCs and VCC liners in fabrication; progress on track
- ISFSI expansion design and site A/E essentially complete
- Kewaunee county permits approved
- VCC construction campaign started in May
- Operating procedures under development
Summary and Conclusion

- **U.S. Decommissioning Trend on the Rise** – 5 reactors shutdown since 2013
  - A few other reactors are at risk of shutdown due to economic reasons (low power costs in deregulated markets)

- **Safety, Security and Economics drive a sound decommissioning strategy**

- **In fact, all of the shut down sites (those with no operating reactors) have implemented or are planning to promptly implement dry storage**
  - The inherent safety of dry cask storage and the potential for a smaller plant security footprint and associated benefits is a key driver for prompt defueling of shutdown reactors.

- **Two recent NAC projects demonstrate that dry storage technology selection plays a key role in the safety and economics of a decommissioning defueling operation.**
  - The Zion spent fuel transfer was the largest dry storage campaign ever implemented in the U.S. and it was completed in about a year.
  - Lessons learned and further innovations are being leveraged at the Kewaunee project to achieve plant defueling a just 3.5 years after plant shutdown. This is about two years earlier than originally planned.
To meet U.S. regulations, a Damage Fuel Can (DFC) must confine gross fuel particles, debris, or damaged assemblies to a known volume within the cask, demonstrate that compliance with the criticality, shielding, thermal, and structural requirements are met; and permit normal handling and retrieval from the cask.