Lessons Learned from EPRI Decommissioning Program
Radioactive Waste and Spent Fuel Management

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Overview

- Decommissioning involves the safe disposition of a very large quantity of radioactive, hazardous and conventional waste.
- Decommissioning projects are completed or are nearing completion in the US, Germany and Spain.
  - Various waste disposal and interim storage options have been used and successful methods have been developed for handling the large quantities of decommissioning waste.
  - Experiences provide important lessons learned and successful strategies that can reduce decommissioning cost, schedule and complexity.
- EPRI has captured these lessons learned in an EPRI report to be published in the Spring of 2015.
## Radioactive Waste Volumes for Selected US Decommissioning Projects

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Plant Name</th>
<th>Connecticut Yankee ft³ (m³)</th>
<th>Maine Yankee ft³ (m³)</th>
<th>Rancho Seco ft³ (m³)</th>
<th>San Onofre Unit 1 ft³ (m³)</th>
<th>Trojan ft³ (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>Connecticut Yankee</td>
<td>3,754,572 (106,318)</td>
<td>3,224,000 (91,290)</td>
<td>608,713 (17,237)</td>
<td>1,680,558 (47,588)</td>
<td>Not Available</td>
</tr>
<tr>
<td>Class B &amp; C</td>
<td>Maine Yankee</td>
<td>10,354 (293)</td>
<td>20,000 (600)</td>
<td>3,284 (93)</td>
<td>1,050 (30)</td>
<td>Not Available</td>
</tr>
<tr>
<td>Greater Than Class C (GTCC)</td>
<td>Rancho Seco</td>
<td>Not Available</td>
<td>Not Available</td>
<td>378 (11)</td>
<td>96 (3)</td>
<td>Not Available</td>
</tr>
<tr>
<td>Total</td>
<td>San Onofre Unit 1</td>
<td>3,764,926 (106,611)</td>
<td>3,244,000 (91,860)</td>
<td>612,375 (17,341)</td>
<td>1,681,704 (47,621)</td>
<td>275,000 (7,790)</td>
</tr>
</tbody>
</table>

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IAEA Waste Classifications

- **HLW**: high level waste (deep geologic disposal)
- **ILW**: intermediate level waste (intermediate depth disposal)
- **VSLW**: very short lived waste (decay storage)
- **LLW**: low level waste (near surface disposal)
- **VLLW**: very low level waste (landfill disposal)
- **EW**: exempt waste (exemption / clearance)

Radioactivity level vs. half-life graph.
## Comparison of Estimated Waste Volume for European Plant to Actual Values for US Plants

<table>
<thead>
<tr>
<th>Waste Type (U.S. Classification)</th>
<th>Estimate for European Plant ft³ (m³)</th>
<th>Maine Yankee (860 MWe-PWR) ft³ (m³)</th>
<th>Rancho Seco (913 MWe-PWR) ft³ (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low Level and Low Level (Class A)</td>
<td>102,800 (2,911)</td>
<td>3,244,000 (91,290)</td>
<td>608,713 (17,237)</td>
</tr>
<tr>
<td>Intermediate Level (Class B and C)</td>
<td>86,840 (2,459)</td>
<td>20,000 (600)</td>
<td>3,284 (93)</td>
</tr>
<tr>
<td>Greater Than Intermediate Level (GTCC)</td>
<td>3,850 (109)</td>
<td>Not Available</td>
<td>378 (11)</td>
</tr>
<tr>
<td>Total</td>
<td>193,500 (5,479)</td>
<td>3,244,000 (91,860)</td>
<td>612,375 (17,341)</td>
</tr>
</tbody>
</table>

### Decommissioning Strategy

<table>
<thead>
<tr>
<th></th>
<th>Decontaminate Buildings and Equipment to Clearance Levels</th>
<th>Little Decontamination of Buildings and Equipment</th>
<th>Decontamination of Buildings, Little Decontamination of Equipment</th>
</tr>
</thead>
</table>
Global Radioactive Waste Disposal Facilities

- The majority of nations employ a waste classification program that is based in whole or part, on the IAEA system with a few using a U.S. based classification approach.

- Most countries have access to a disposal site for low and intermediate level waste and some include an option for very low level waste (VLLW).

VLLW trench and waste emplacement at ANDRA’s Morvilliers facility.
Metal/Large Component Processing Options in Europe

- Waste Processors used to reduce waste storage and/or burial in:
  - Germany (>90% of waste from decommissioning released or recycled)
  - Finland
  - Spain
  - Sweden
  - Switzerland
  - UK

- Primary Waste Processing Facilities:
  - Siempelkamp in Krefeld, Germany
    - Receives mostly segmented metal items
    - Most recycled to the nuclear industry after melting
  - Studsvik in Nyköping, Sweden
    - Accepts large components intact
    - Most metal free released or released for recycle into general industry after melting
  - Studsvik in Workington, U.K
    - Mostly metal scrap
    - Decontamination and segmentation
    - Processing Goal: Clearance of materials

Siempelkamp
Induction Furnace
EPRI Report Decommissioning Waste Management Benchmarking Results

- Regulatory, social and economic drivers for waste management may vary substantially between countries.
- For example:
  - Clearance of material and/or disposal as very low level waste (VLLW) are not available waste management options in all countries;
  - Final waste acceptance criteria, including waste packaging requirements, have not been developed in all countries;
  - Centralized waste processing facilities capable of handling large components are available only in a limited number of countries;
  - One-piece disposal of large components is not an acceptable practice in most countries as it is in the U.S.; and
  - The cost for disposal of Class A, B and C waste (or LL/ILW) is typically much lower in the US than in most other countries
Decommissioning Waste Management Lessons Learned and Key Best Practices (1/5)

- Use as large packages as is practical, consistent with disposal facility limitations – The use of large packages saves on labor in a number of ways:
  - Allows fewer cuts of piping and other components
  - Less package handling and shipping paperwork preparation
- Load the packages as close to the removal areas as is practical – Material handling can be a very time consuming task
- Locate the waste shipping area away from the waste removal and processing areas as shipping packages immediately after loading of the waste is not practical
- Need staging areas for box loading activities – It has been shown during decommissioning that building demolition debris is created much faster than it can be loaded into packages
Decommissioning Waste Management Lessons Learned and Best Practices (2/5)

- Provide adequate space for waste staging and shipping operations
- Experiences at some sites related to the mechanical aspects of concrete and soil remediation have offered important lessons learned. They include:
  - The need to tent some areas at Connecticut Yankee during remediation of buildings and soil due to high alpha contamination levels.
  - The need to dewater a large portion of the Radiological Control Area at Connecticut Yankee to allow remediation below the water table.
  - Remediation of contamination in the discharge and intake canal may require special sediment dewatering techniques such as agglomeration to increase particle size, filter presses or large filter socks. The dewatered sediment will also need to be dried.
Decommissioning Waste Management Lessons Learned and Best Practices (3/5)

- In the US where the VLLW option is not available, disposal of very low level building demolition debris at a RCRA Class C disposal facility under a 10 CFR 20.2002 exemption presents a lower cost option for disposal.

- Complete and thorough characterization of a facility for radioactive and hazardous materials prior to decommissioning is essential to minimize uncertainties in decommissioning work scope.

- The cost of free release surveys of complex piping systems is high and the probability of success is uncertain. The majority of decommissioning projects in the U.S. have found that removal and discard is the best approach for dealing with contaminated piping.

- Experience with the chemical decontamination of primary and auxiliary systems has been shown to result in large savings in radiation exposure to workers and has facilitated the disposal of the systems decontaminated.
Decommissioning Waste Management Lessons Learned and Best Practices (4/5)

- The use of rail shipments can be beneficial for some equipment applications, but rail shipments can introduce additional challenges.
- There will be significant contaminated at the end of a decommissioning. Some potential disposition paths for contaminated equipment include:
  - Equipment, such as scabblers and excavators that has been used in high contamination areas that will likely need to be disposed of as radioactive waste
  - Consideration should be given to leasing reusable shipping boxes with the agreement that the owner retrieve them contaminated at the end of the project.
  - Disposition of radioactive sources may be a relative large cost at the end of the decommissioning. Potential cost savings measures:
    - Give them to another licensee instead of paying for waste disposal.
    - Have the manufacturer retrieve high activity calibration sources at no cost
  - Some contaminated specialty equipment such as radiation protection survey meters generally can be sold to another site.
Decommissioning Waste Management Lessons Learned and Best Practices (5/5)

- Hazardous waste remediation can have a major impact on the decommissioning of a nuclear plant.

- Key issues identified at an EPRI Hazardous Waste Material Remediation Technology Workshop in 1999:
  - The Big Rock Point plant estimated that approximately 60% of painted components contain polychlorinated biphenyls (PCB) above 50 ppm. This level of concentration required disposal as regulated material.
  - Yankee Rowe reported that the use of "scoping surveys" and site history information proved to be indispensable in guiding their efforts.
  - Big Rock Point has found that incorporating waste identification and minimization actions into the work package planning process was a key element to effectively address hazardous waste remediation.
  - The US Department of Energy’s Large Demonstration Program has demonstrated several innovative hand-held instruments directed at real-time analysis of key materials (for example, lead, PCBs, and metal composition).
Selected EPRI Reports Related to Decommissioning Waste Management


Current Approaches to Management of High Level Waste (Includes Spent Fuel)
Status of Disposal of High Level Waste (HLW)

- In most countries, deep geological disposal is considered the preferred approach.
- No disposal site for commercial HLW is currently in operation in any country.
  - Finland, France, and Sweden are farthest along in disposal site processes.
  - Waste Isolation Pilot Plant operational in the US for certain types of defense program HLW.
- Interim storage is the current approach in all countries.
- Programs to develop deep geological sites are ongoing in all countries with mature nuclear power industries.
  - Progress and approaches vary substantially.
Geological Disposal Site Design

Design Characteristics

- Defense in depth
  - Natural barrier(s) based on geological and hydrogeological conditions
  - Engineered barriers including waste package design

Source: Reference 1
Geological Disposal Site Design

Siting Process Steps

- Define implementing organization(s) and funding scheme
- Screen, select and characterize disposal site location(s)
- Develop disposal concept
- Establish protocol for stakeholder and public involvement
- Perform performance and safety assessments (PA and SA)
- Facility licensing
- Facility construction
Disposal Site Selection

- Primary geology types considered suitable natural barriers
  - Crystalline rock formation (igneous and metamorphic)
  - Salt formations
  - Impermeable clay or shale (argillaceous) sedimentary formations
  - Volcanic tuff

<table>
<thead>
<tr>
<th>Geology</th>
<th>Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystalline rock (e.g., granite and gneiss)</td>
<td>Sweden, Finland, Japan, Canada</td>
</tr>
<tr>
<td>Argillaceous rock (e.g., clay and shale)</td>
<td>France, Switzerland, Belgium</td>
</tr>
<tr>
<td>Salt</td>
<td>U.S. (WIPP), Germany</td>
</tr>
<tr>
<td>Volcanic tuff</td>
<td>U.S. (Yucca Mountain)</td>
</tr>
</tbody>
</table>

Source: Reference 1
Disposal Concept

- Determined by site characteristics and performance requirements
- Generally robust waste disposal packaging
- Waste retrieval may be considered

Swedish HLW Disposal Concept (spent fuel)

Source: Reference 3
Stakeholder and Public Involvement

- Adaptive Phased Management is generally the preferred approach
  - Stakeholder and public involvement during all phases of siting process, including “technical” phases
- Site selection may be voluntary (e.g., Belgium) or prescribed (e.g., Finland)
Performance and Safety Assessments

- Key factors are assessment timeframe and risk metrics
- Varying approaches on importance of engineered safety barriers to overall site performance in meeting prescribed safety goals over the prescribed time period
  - Performance of engineered safety barriers a key component in Sweden, Finland and Japan
  - Performance of natural barriers assumed to provide the predominant contribution to meeting safety goals in France, Belgium and Switzerland
## PA/SA Summary by Country (1/2)

<table>
<thead>
<tr>
<th>Country</th>
<th>Assessment Timeframe</th>
<th>Safety Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>Not specified; assessments performed for $&gt;10^6$ year period</td>
<td>$&lt;0.3$ mSv/year</td>
</tr>
<tr>
<td>Canada</td>
<td>10000 years</td>
<td>$&lt;0.3$ mSv/year</td>
</tr>
<tr>
<td>Finland</td>
<td>0-10000 years</td>
<td>$&lt;0.1$ mSv/year Radioactivity release limits Qualitative</td>
</tr>
<tr>
<td></td>
<td>100000 to 1000000 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1000000 to $10^6$ years</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>0-10000 years</td>
<td>0.25 mSv/year Qualitative (consider 0.25 mSv/year goal)</td>
</tr>
<tr>
<td></td>
<td>1000000 to $10^6$ years</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>0-$10^6$ years</td>
<td>Likely event (probability &gt;0.1): risk $&lt;10^{-4}$ Less likely event (probability &lt;0.1): risk $&lt;10^{-3}$</td>
</tr>
<tr>
<td>Japan</td>
<td>Not specified; assessments performed for $&gt;10^6$ year period</td>
<td>$&lt;0.3$ mSv/year</td>
</tr>
</tbody>
</table>
## PA/SA Summary by Country (2/2)

<table>
<thead>
<tr>
<th>Country</th>
<th>Assessment Timeframe</th>
<th>Safety Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spain</td>
<td>Not specified</td>
<td>Individual risk $&lt;10^{-6}$; $&lt;0.1$ mSv/year in critical group</td>
</tr>
<tr>
<td>Sweden</td>
<td>100000 years for risk; assessments to $10^6$ years</td>
<td>Individual risk $&lt;10^{-6}$</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Not specified; assessments performed for $&gt;10^6$ year period</td>
<td>Likely event: $&lt;0.1$ mSv/yr Less likely event: risk $&lt; 10^{-6}$</td>
</tr>
<tr>
<td>Taiwan</td>
<td>Not specified; assessments performed for $&gt;10^6$ year period</td>
<td>0.25 mSv/year</td>
</tr>
<tr>
<td>UK</td>
<td>Not specified; assessments performed for $&gt;10^6$ year period</td>
<td>Risk $&lt; 10^{-6}$/year</td>
</tr>
<tr>
<td>US</td>
<td>10000</td>
<td>Dose 0.15 mSv (life time) to an individual Radioactivity release limits</td>
</tr>
</tbody>
</table>
Disposal Site Status and Outlook

- Finland, France and Sweden are far along in the site selection, design, assessment and licensing process
- Progress made previously in Germany and US, but programs stalled; reinitiating efforts
- Substantial R&D in progress in Belgium, Japan, Switzerland and UK
- Initial site selection underway in Canada and China
- Spain has not *formally* committed to deep geological disposal
- No progress in South Korea
Interim Storage of HLW

- HLW, including spent nuclear fuel, generally stored on plant sites
- Longer-term centralized storage being actively pursued in several countries
  - Siting process has begun in the US
  - Conceptual process being developed in Belgium and Spain
  - Long-term integrity of storage canisters is a technical concern
    - Particularly for high burn up spent fuel
Together…Shaping the Future of Electricity