Lessons Learned from EPRI Decommissioning Program

Decommissioning Pre-Planning Overview

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IAEA Technical Meeting on Plant Life Management During the Transition from Operation to Decommissioning at NPPs

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Discussion Topics

- Who is EPRI?
- Decommissioning Strategy and Decisions
- Transition from Operation to Decommissioning
- Ten Key Decommissioning Questions
- Decommissioning Cost: Experience
EPRI’s Mission

Advancing *safe, reliable, affordable*, and *environmentally responsible* electricity for society through global collaboration, thought leadership and science & technology innovation.
Three Key Aspects of EPRI

**Independent**
Objective, scientifically based results address reliability, efficiency, affordability, health, safety, and the environment

**Nonprofit**
Chartered to serve the public benefit

**Collaborative**
Bring together scientists, engineers, academic researchers, and industry experts
EPRI Decommissioning Technology Program Overview

- **Program Objective**
  - To provide technical guidance for the planning and conduct of facility decommissioning

- **Program Strengths**
  - Documentation of >20 years experience in the successful decommissioning of commercial power plants
  - R&D results covering all critical technical areas in plant decommissioning
    - Planning/Regulatory
    - Dismantlement
    - Waste Management
    - Site Characterization and Release
  - Offers a forum for utilities to share current experiences and state-of-the-art technologies for plant decommissioning
  - Program results applicable to all plant designs and all countries
  - > 100 EPRI Reports Published
Decommissioning Options

- US Regulation: Decommissioning (license termination) *must* be completed within 60 years of permanent plant shutdown
- The NRC defines three approaches to decommissioning*
  - DECON: Prompt dismantlement
  - SAFSTOR: Plant defueled and maintained in a safe condition
  - ENTOMB: Plant permanently enclosed within a robust structure
- Similar options outside of the US
  - Time to complete decommissioning varies

Examples of Timing of Dismantlement

**Prompt Dismantlement**
- Shippingport
- Trojan
- Big Rock Point
- Yankee Rowe
- Wurgassen
- Connecticut Yankee
- Maine Yankee
- Stade

**Safestor then Dismantlement**
- Humboldt Bay
- San Onofre 1
- Zion 1 & 2
- Rancho Seco
- Caorso
- Latina
- Trino
- Garigliano

**Safestor**
- Douglas Point
- Dresden 1
- Indian Point 1
- TMI 2
- Fermi 1
- Millstone 1
- Peach Bottom 1
- Pickering 2 & 3
Motivation: Prompt Dismantlement

- **Efficiency**
  - Knowledgeable plant staff
  - Plant equipment operational

- **Economics**
  - Release of valuable land

- **Risk avoidance**
  - Potential long term liability
  - Waste disposal cost and site availability
  - Cost escalation/negative investment return from Decommissioning Fund

- **Public perception/governmental pressure**
Motivation: Safe Storage

- **Efficiency**
  - Lower worker exposure due to radioactive decay
  - Other operating units on multi-unit sites
  - Potential for technology advancement
  - Lack of disposal pathways

- **Economics**
  - Decommissioning Fund not fully funded
  - Lower waste costs due to radioactive decay
Decommissioning Decisions for the Future Use of the Site

- Setting the end goal of decommissioning impacts key decommissioning strategies, site release limits and costs

- Site End State Decisions:
  - Utility retains ownership or site released to public?
  - Site released with buildings demolished or standing?
  - Future use of the site:
    - Unrestricted Release:
      - Residential (Resident Farmer)
      - Industrial
    - Restricted Release: Institutional controls enforce land use restrictions and allow higher release limits
Decommissioning Strategy and Decisions
Future Use of the Site

- Important to decide on decommissioning end state early in the planning process.
- Involves/Requires discussions with regulators
- Site Release Criteria and Limits:
  - Radionuclide concentrations set by regulator or dose based (i.e., 0.25 mSv/yr dose limit in U.S.)
  - Resident Farmer Scenario – Relatively lower radionuclide concentration limits allowed
  - Industrial Use Scenario – Relatively higher concentrations allowed
Future Use of the Site & Spent Fuel Storage
Connecticut Yankee – Resident Farmer Scenario

Dry Fuel Storage Facility
Future Use of the Site & Spent Fuel Storage
Rancho Seco – Industrial Use Scenario

Intermediate Level Waste Storage Facility
DecommissioningStrategy and Decisions - Full System Decontamination

- Conducted before major plant systems are retired (e.g. reactor coolant pumps)

- Facilitates Decommissioning
  - Reduces contamination within plant systems
  - Reduces dose rates to workers during decommissioning

- Recent Industry Experiences: José Cabrera (Spain), Neckarwestheim, Unterwesser, Isar and Philippsburg (Germany)

- EPRI Decontamination for Decommissioning (DfD) Process Available
Other Decommissioning Strategies and Decisions

- Reactor Vessel and Internals Disposition
  - Dispose whole/intact (e.g. grouted)
  - Dispose with segmented internals (intact vessel)
  - Dispose segmented vessel and internals
  - Technology

- Waste Management and Disposal
  - Availability of radioactive waste disposal site
  - Availability of very low level waste category and clearance level
  - Availability of industrial waste sites
Decommissioning Process

- Typical Decommissioning Sequences During Phases
  - Pre-Decommissioning (Transition) Phase
  - Phase 1: Moving Fuel to Dry Fuel Storage
  - Phase 2: Highly Contaminated Systems Removal
  - Phase 3: Remaining Systems Being Removed
  - Phase 4: Buildings Being Decontaminated
  - Phase 5: Final Remediation and Site Release
Pre-Decommissioning (Transition) Phase

- Large volume of Licensing and Engineering work need to change the Design Basis of the plant to Permanently Defueled
  - Safety Analysis Report
  - Downgrade of Systems
  - Technical Specifications
  - Program and Procedures

- Create a Decommissioning Plan
  - Exposure and Waste Estimates
  - Dismantlement and Decontamination Methods to be used
  - Site Release Criteria Development and Final Status Survey Methods
Phase 1

- Moving Fuel to Dry Fuel Storage or Off-site
  - Necessary Systems Repowered
  - Plan/Contract for Major Projects (i.e. Chemical Decon, Reactor Removal)
  - Reason Done First:
    - Allows Reduction in Secure Area
    - Allows Downgrading and Removal of Unnecessary Systems
Phases 2 and 3

- Phase 2: Highly Contaminated Systems Removal
  - Primary Component Removal and Shipment for Disposal
  - Fuel Pool Drained and Decontaminated
  - Reason Done Second:
    - By Reducing Radiation Sources remainder of removals facilitated
    - Installed Plant Ventilation System Needed for Airborne Contamination Control

- Phase 3: Remaining (Lower Activity) Systems Removed
  - Reason Performed Third:
    - Systems Need to be Removed to Allow Building Decontamination
    - Less Building Ventilation Needed for Airborne Control (Use Portable Equipment)
Phases 4 and 5

• Phase 4: Building Decontamination to Site Release Limits
  – Separation of contaminated and non-contaminated materials (e.g. concrete)
  – Waste management and optimization
  – Outlying areas of the site may be released from the license

• Phase 5: Final Remediation and Site Release
  – Building Demolition (if performed)
  – Remediation of Soil and Groundwater
  – Final Site Survey Complete, License Terminated
Ten Key Decommissioning Questions

1. What are the waste disposal options available?
2. What is the required form/packaging of the waste for disposal?
3. What are the disposition options for the spent fuel?
4. What is the end state of the site going to be?
5. What is the site release criteria set by the regulator?
6. What options do I have in setting the site release limits (i.e., residential, industrial, other scenarios)?
7. Do clearance and/or recycle regulatory criteria exist?
8. Do I promptly decommission or wait for the remaining plants on site to permanently shutdown?
9. Do I perform a full system chemical decontamination?
10. Does the regulator have a required schedule for preparation of decommissioning documents and/or completion of the decommissioning?
## Comparison of Connecticut Yankee and Rancho Seco

<table>
<thead>
<tr>
<th>Aspect of Decommissioning</th>
<th>Connecticut Yankee (CY)</th>
<th>Rancho Seco</th>
<th>Result of Difference for Rancho Seco</th>
</tr>
</thead>
<tbody>
<tr>
<td>Future Use</td>
<td>Resident Farmer</td>
<td>Industrial</td>
<td>Higher Release Limits, Less Decontamination and Waste</td>
</tr>
<tr>
<td>Buildings Surveyed for Release</td>
<td>No</td>
<td>Yes</td>
<td>Higher Survey Cost, Much Less Waste</td>
</tr>
<tr>
<td>Radiological Status of Buildings &amp; Land</td>
<td>Contamination High incl. Alpha</td>
<td>Little Contamination</td>
<td>Lower Decontamination Costs and Much Less Waste</td>
</tr>
<tr>
<td>Activity in Reactor Internals</td>
<td>Very High</td>
<td>Approximately 1/10&lt;sup&gt;th&lt;/sup&gt; of CY</td>
<td>Easier, Less Costly Internal Segmentation</td>
</tr>
<tr>
<td>Materials Surveyed for Release</td>
<td>Generally No</td>
<td>Yes if Likely to be Successful</td>
<td>Less Waste and Disposal Costs</td>
</tr>
<tr>
<td>Reactor Segmented</td>
<td>No</td>
<td>Yes</td>
<td>Lower Disposal Costs</td>
</tr>
<tr>
<td>Groundwater Contamination</td>
<td>Yes</td>
<td>No</td>
<td>No Waste, Very Low Survey Costs</td>
</tr>
<tr>
<td>Final Survey Instrumentation</td>
<td>Generally Hand Held</td>
<td>Portable Gamma Spectroscopy</td>
<td>Saved Time and Labor Costs</td>
</tr>
<tr>
<td>Total Decom. Cost</td>
<td>$850 Million</td>
<td>$424 Million</td>
<td>Result of Factors Above</td>
</tr>
</tbody>
</table>
Transition Period Activities
**Typical Goals During Early Portions of Decommissioning – US Experience**

- Reduction in Technical Specifications
- Reduction in Operating Systems
- Reduction/Modification of Necessary Programs
- Historical Site Assessment/Site Characterization
- Eliminate Need for Off-site Emergency Plan
- Perform Early Decommissioning Projects
  - Full System Chemical Decontamination
  - Asbestos Insulation Removal
  - Modify Building Containing Fuel Pool to Spent Fuel Pool Island (SFPI)
  - Move Control Room
  - Collapse Security Boundary to SFPI
- Begin Planning for Long Lead Time Decommissioning Projects
Historical Site Assessments

- Review of plant events to identify areas of the site that may be contaminated with radioactive and/or hazardous materials

Historical Site Assessments include:
- Review of plant documentation (in the U.S. per NRC regulation 10CFR50.75(g)) requires documentation of leaks and spills; modifications of buildings and structures where radiological materials may be used or stored
- Interviews of plant personnel

The first step of site characterization and remediation decision making process
United States Experience with Technical Specification Reduction
US Experience – Examples of Technical Specification Reductions Shortly After Permanent Shutdown

**Technical Specifications Removed**
- Reactor Reactivity Control Systems
- Auxiliary Building Emergency Filter System
- Electric Power Supply Systems
- Special Test Exceptions
- Gaseous Waste Treatment System
- Spent Fuel Pool Storage and Cooling System – Instrumentation
Technical Specification/Emergency Plan Requirements During Wet Fuel Storage

- Technical Specifications Reduced To the Following Once Plant Declared in “Permanently Defueled”:
  - Certified Fuel Handler/Administrative Controls
  - Seismic Monitoring Instrumentation
  - Crane Travel/Load Limitations
  - Pool Water Level/Temperature Limitations
  - Reactivity Controls/Burnup Requirements
  - Fuel Pool Boron Concentration
  - Effluent/Meteorological Instrumentation/Reporting

- Emergency Plan Changes (Site with no Operating Plants)
  - Reduced Radiological Consequences of Accidents
  - Less Personnel On-Call, Reporting Time Requirements
Technical Specification/Emergency Plan Requirements During Dry Fuel Storage

- **Technical Specifications Reduced Further to the Following:**
  - Most Apply During Loading of the Dry Storage Canisters
    - Drying Time/Vacuum Pressure
    - Canister Leak Testing
    - Canister Contamination/Dose Rate Limitations
  - Only Tech Specs Applicable After Fuel Loading Complete:
    - Cask Heat Removal System Operable (Passive System)
    - Surveillance After Natural Phenomena (i.e. Earthquake)

- **Further Emergency Plan Changes**
  - No Credible Accidents, No Effluents
  - No On-Call Requirements
  - Security Response Available
  - Any need for Clean-up Personnel arranged after the event
Other Potential Document Changes During Pre-Shutdown Period – US Experience

- **Regulatory Required in the US:**
  - Plant Procedures
  - Plant Program Descriptions
  - Technical Requirement Manual
  - 10 CFR 50.59 screenings/determinations,
  - Safety classification change documentation, as required.
  - Radiological Effluent Monitoring/Off-Site Dose Calculation Manual

- **Documents to Optimize Efficiency of the Decommissioning:**
  - Prepare Strategic Plans for the Decommissioning
  - Define the Decommissioning Organization/Human Resources Plan
  - Perform Historical Site Assessment (Precursor to Site Characterization)
  - Prepare Site Characterization Plan
  - Prepare Communication Plan
  - Redesign Work Control Process
  - Evaluate Chemical Decontamination Process and Award Contract, if applicable
Summary of Early Decommissioning Tasks and Regulatory Submittals

- Performance of certain tasks (i.e., Historical Site Assessment) and the planning and preparation for early decommissioning projects before shutdown can facilitate decommissioning and reduce overall costs.
- Preparation of regulatory documents needed prior to and during the early periods of a decommissioning is a major effort.
- The early periods of the decommissioning can proceed more efficiently if preparation of regulatory documents begins 2 or 3 years prior to plant shutdown.
- Preparations of other (non-regulatory) studies and plans can reduce cost during the early periods of a decommissioning.
Decommissioning Cost Experience
Decommissioning Costs: Summary

- Decommissioning Costs for Eight U.S. Plants Summarized in EPRI Report 1023025, 2011
  - Based primarily on publically available information
- Staffing Determined to be Highest Cost for Each Plant
  - 29 to 52% of cost
  - Structure/Component Dismantlement second highest cost, 19 to 26%
  - Waste Disposal 17 to 27% of Cost

Cost Categories as Average Percentage of Total Costs

- Dismantlement: 23.6%
- Waste: 19.0%
- Staffing: 43.5%
- Other: 13.9%
Decommissioning Costs: Summary

Decommissioning Cost by Category

Percentage of Total Cost

Dismantlement
Waste
Staffing
Other

Plant
A
B
C
D
E

0
10
20
30
40
50
60
Decommissioning Costs: Dismantlement Costs

- No Significant Trend in Cost versus Plant Size
- Largest Plant had Relatively Low Dismantlement Cost
  - Contributing Factors:
    - Buildings Left Standing
    - Extended SAFSTOR Period
    - Short operation

In Most Cases this Category Includes Decontamination Costs
Decommissioning Costs: Waste Costs

Waste Cost Percentage of Total Cost

<table>
<thead>
<tr>
<th>Plant</th>
<th>Waste Cost Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15</td>
</tr>
<tr>
<td>B</td>
<td>25</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
</tr>
<tr>
<td>E</td>
<td>27</td>
</tr>
<tr>
<td>F</td>
<td>32</td>
</tr>
<tr>
<td>G</td>
<td>23</td>
</tr>
<tr>
<td>H</td>
<td>26</td>
</tr>
</tbody>
</table>
# Decommissioning Costs: Waste Costs

<table>
<thead>
<tr>
<th>Waste Classification</th>
<th>Plant B</th>
<th>Plant C</th>
<th>Plant D</th>
<th>Plant E</th>
<th>Plant F</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Not Available</td>
<td>1,680,558</td>
<td>608,970</td>
<td>658,885</td>
<td>3,754,572</td>
</tr>
<tr>
<td>B/C</td>
<td>Not Available</td>
<td>1,050</td>
<td>3284</td>
<td>3,648</td>
<td>10,354</td>
</tr>
<tr>
<td>GTCC</td>
<td>Not Available</td>
<td>Not Available</td>
<td>378</td>
<td>17</td>
<td>Not Available</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3,244,000</td>
<td>1,681,608</td>
<td>612,254</td>
<td>658,885</td>
<td>3,764,926</td>
</tr>
<tr>
<td><strong>Average Transport + Disposal Cost ($/ft³)</strong></td>
<td>51</td>
<td>19</td>
<td>137</td>
<td>172</td>
<td>72</td>
</tr>
</tbody>
</table>
Factors Affecting Dismantlement Costs

- **Primary Direct Factors**
  - Facility End State (“Green Field” vs “Industrial Use”)
  - Degree of contamination of large structures
  - Site and material release criteria
  - Waste packaging requirements
  - Waste transportation costs
  - Waste disposal costs

- **Primary Indirect Factors**
  - Staffing costs
  - Decommissioning schedule
  - ALARA/Total Worker Exposure goals
Selection of Dismantlement Approach

- **Structure/Component Specific**
  - Specific activity levels/waste classification
  - Extent, distribution and degree of contamination
  - Size and material mass
  - Available dismantlement methods

- **Direct Costs Must Be Balanced with Indirect Costs**
  - Direct Cost = Dismantlement Cost + Waste Processing and Packaging Cost + Waste Transportation and Disposal Costs
  - Indirect Costs = Critical Path Schedule Impact (Mostly Support Staffing Cost) + Net Exposure Impact
Dismantlement Approach Example 1

**Concrete Structures in Radiological Control Areas; Green Field Case**

- Specific activity is low
- General contamination levels generally low; limited potential to change waste classification
- Contamination extensive and not limited to accessible surfaces
- Very large surface areas/challenging accessibility
- Very time consuming to decontaminate
- Dismantlement typically on the direct critical path

- Large RCA Concrete Structures Typically Demolished and Disposed of as Class A Waste without Decontamination or Attempts to Release Material
  - Decontamination Limited to Localized Areas
Dismantlement Approach Example 2: Reactor Vessel

- High specific activity
- High surface contamination
- Some activated metal
- Large volume and mass
- Decontamination to change waste classification possible

- Reactor Vessel typically segmented
- Material segregated and packaged for disposal
- Material may be decontaminated to reduce waste classification and/or to allow release or recycling (if permitted)
Evaluation of Dismantlement Approach: Considering Cost Factors (1/4)

- Key Inputs
  - Radiological characterization data
    - Total activity content
    - Nuclides present
    - Extent of contamination
    - Fixed or loose contamination, activated metal
  - Physical Characteristics
    - Volume and weight
    - Material type and condition
    - Surface roughness (weld, porosity, cracks, etc.)
Evaluation of Dismantlement Approach: Considering Cost Factors (2/4)

- Key Inputs (continued)
  - Decontamination and Dismantlement techniques available
    - Field-proven/risks
    - Degree of effectiveness
    - Application cost
    - Application schedule
    - ALARA considerations
    - Secondary wastes
    - Critical path impact
Evaluation of Dismantlement Approach: Considering Cost Factors (3/4)

- Key Inputs (continued)
  - Waste characteristics
    - Classification
    - Volume and mass
    - Handling techniques
    - Ability to segregate
    - Ability to release, recycle or decontaminate (post-dismantlement)
Evaluation of Dismantlement Approach: Considering Cost Factors (4/4)

- Key Inputs (continued)
  - Waste cost
    - Packaging requirements
    - Transportation costs
    - Disposal costs
    - ALARA considerations
  - Project Schedule Impact
    - Time added to overall schedule
    - Affects overall staffing costs

Facility Modification (e.g., adding Rail Spur) may Reduce overall Transportation Costs

Disposal Site may Broker Lower Costs for High Volumes of Lower Activity Waste
Related References: EPRI Reports

- #3002007551, *Guidance for Transitioning from Operation to Decommissioning for Nuclear Power Plants*, 2016
- #1023025, *Decommissioning Experiences and Lessons Learned: Decommissioning Costs*, 2011
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