

# **Nuclear Power Plant Decommissioning in U.S.**

**U.S. Nuclear Regulatory Commission Guidelines,  
Process and Decommissioning Status**

**Jeju, Republic of Korea**

**May 17, 2017**

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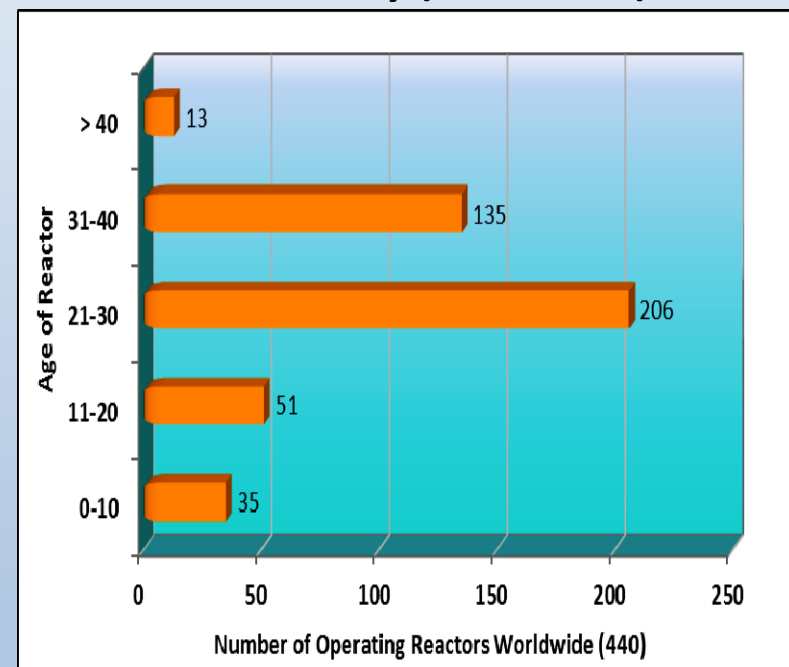
# **Outline of Presentation**

- **Global Status of Decommissioned NPPs**
- **NRC Regulation of Decommissioning Process**
- **Decommissioning approaches and strategies of licensees**
- **Status of Decommissioning in U.S.**
- **Dismantlement Case Studies in Pictures**
- **Cost of Decommissioning – Actuals and Future Estimates**
- **Implications for ROK Decommissioning Decisions**
- **Potential areas of cooperation**

# Global History of Decommissioned Nuclear Reactors

- Total number of reactors built around the world: ~600; 441 still operating as of end of 2015 = 11% of world's electricity
- Power reactors shutdown: 159 (including experimental and prototypes),
- 17 fully dismantled; over 50 in process of dismantling.
- Over 50 in Safstor, 3 have been entombed, others still deciding on decommissioning strategy
- Experience in the USA has varied: 13 power reactors in Safestor mode; and 16 (mostly single-unit plants) are in or have completed Decon.

Age Profile of Operating Reactors Globally (as of 2011)



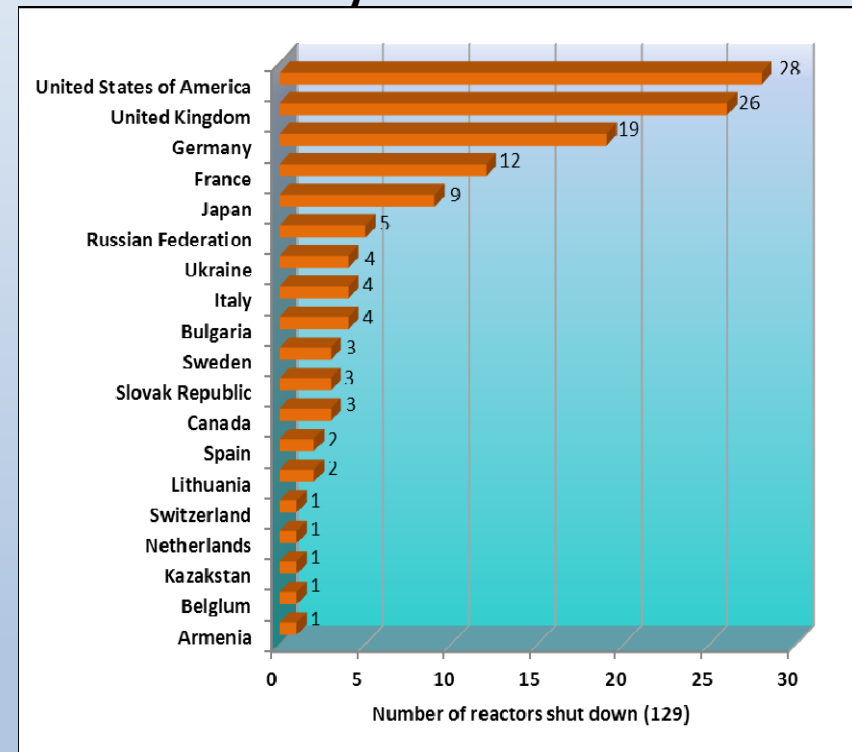
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# Basic Steps in Decommissioning and Dismantlement

- **Characterizing, decontaminating and dismantling reactors and plant structure**
- **Removal of radioactive and other wastes**
- **Site cleanup**
- **Ensuring non-release of potentially harmful radioactive materials into environment;**
- **Site compliance with safety decommission regulations**

**Three possible decommissioning pathways: DECON, SAFSTOR, ENTOMB**

**Number of Nuclear Power Reactors Shutdown by Country (as of 2011)  
Currently 159 as of 2015**



[https://na.unep.net/geas/getUNEPPageWithArticleIDScript.php?article\\_id=70](https://na.unep.net/geas/getUNEPPageWithArticleIDScript.php?article_id=70)

Source: OECD (2002), Deloitte (2006)

**U.S. Regulatory Framework for NPP  
Decommissioning  
(US Nuclear Regulatory Commission)**

# US NRC Nuclear Decommissioning

**NRC Definition:** Safely removing a nuclear facility or site from service and reducing residual radioactivity to permitted level for either release of property for:

- **Unrestricted use, and terminate license; or**
- **Restricted conditions, and terminate license.**

Decommissioning process **begins when licensee decides to permanently cease operations.**

NRC and Agreement States regulate decontamination and decommissioning with **goal of license termination**

# NRC's Nuclear Decommissioning Program

- (1) **Develops regulations and guidance** to assist NRC staff
- (2) **Conducts research** to develop data, techniques, and models for assessing potential public exposure to any release of radioactivity related to decommissioning
- (3) **Reviews and approves** decommissioning plans (DPs) and license termination plans (LTPs); **amendments**
- (4) **Inspects** licensed and non-licensed facilities in decommissioning;
- (5) Develops **environmental assessments** (EAs) and environmental **impact statements** (EISs) to support NRC's reviews of decommissioning activities;
- (6) **Reviews and approves final site status survey reports**;
- (7) **Conduct confirmatory surveys**

## US NRC Compliant Decommissioning Options: DECON, SAFSTOR or ENTOMB

### DECON - Immediate Dismantlement

- Removal of used nuclear fuel rods and equipment (accounts for > 99 % of plant's radioactivity)— **DECON can take 5 years or more**

### SAFSTOR - Deferred Dismantlement - allows for radioactive decay to safe levels before decontamination

- Main plant components remain in place. All fuel removed and put in on-site fuel pools or dry storage.

### ENTOMB – Entombment- no NRC licensee has chosen this approach

US NRC Requirement: **Decommissioning process must be completed within 60 years (50ys SAFSTOR + 10yrs DECON) after shutdown.**



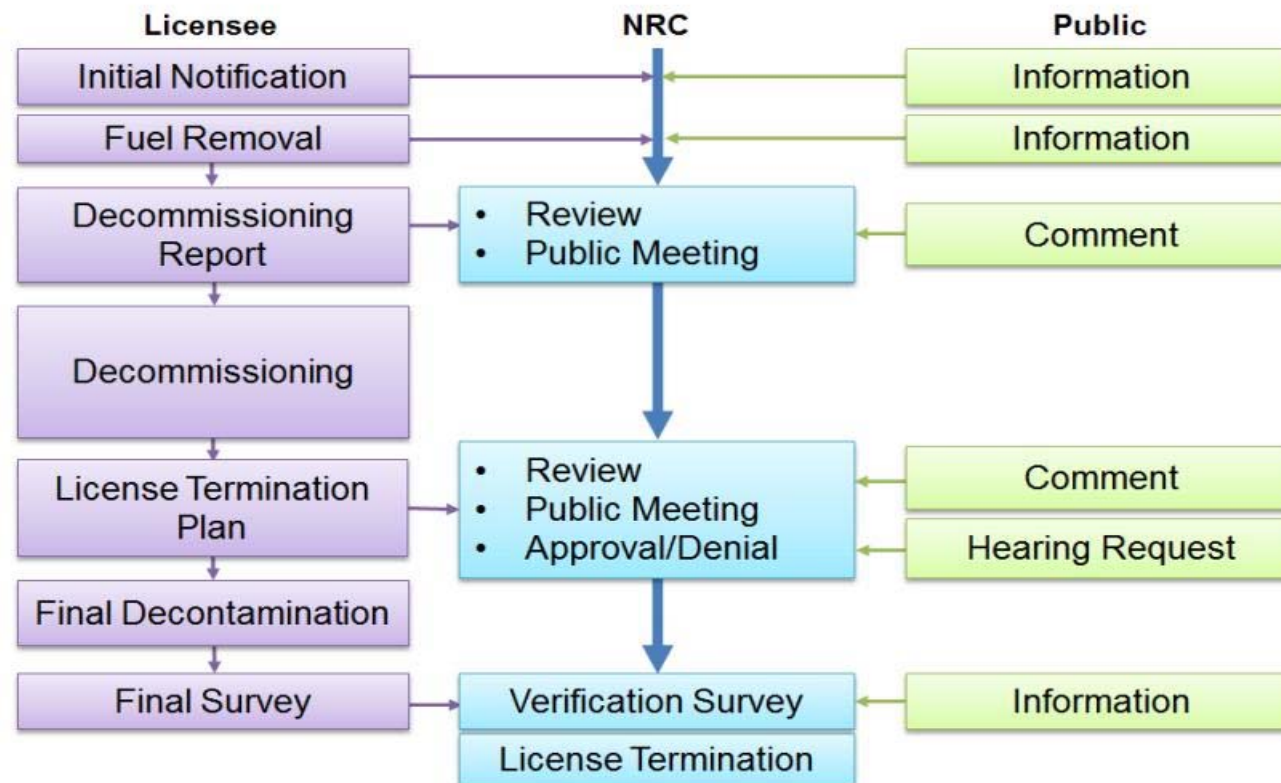
# US NRC Position on Shutdown of NPPs

- Current NRC regulations do not recognize reduction in risk in transitioning from operating to a permanently shutdown, defueled status of NPP in preparation for decommissioning.
- Operating plant requirements for security and emergency preparedness remain in force even when reactor is made inoperable and permanently defueled.

# Summary of NRC NPP Decommissioning Process



## Reactor Decommissioning Process



# Notification

- **Licensee required to submit written notification within 30 days to NRC to certify permanent cessation of operations.**
- **Also, licensee required to submit another written certification to NRC once radioactive nuclear fuel has been permanently removed from the reactor vessel, at which point, owner surrenders authority to operate the reactor or load fuel into the reactor vessel.**



<https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.html>

# Post-Shutdown Decommissioning Activities Report

- Before or **within two years following cessation of operations**, licensee must **submit a PSDAR**- activities description and schedule; cost estimate; discuss environmental impacts (within EIS bund)
- NRC gives notice of receipt of **PSDAR** in *Federal Register*, makes report available **for public comment**, and holds public meetings on PSDAR.
- NRC **does not approve the PSDAR**
- Licensee **cannot perform any major activities until 90 days after NRC receipt of PSDAR**
- Licensee must **notify NRC before performing any activity deviating from PSDAR** schedule and actions.

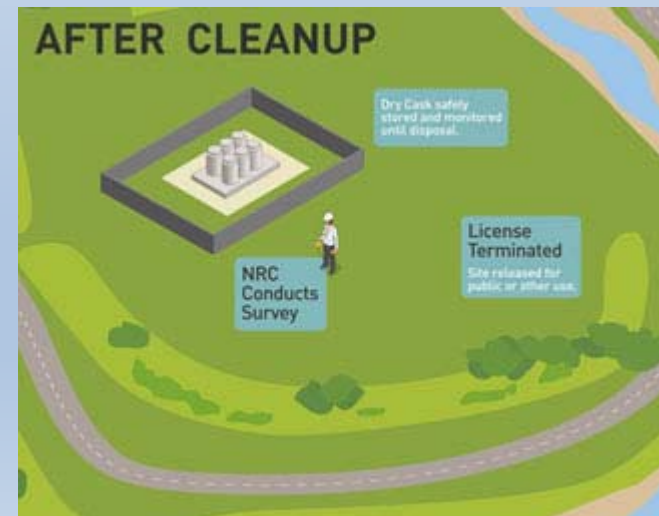
# License Termination Plan (LTP)

- NPP licensee must submit application for license termination (LT).
- **Must submit LTP within two years of expected license termination**
- LTP must precede or accompany LT application to NRC for approval and must include:
  - Site radiological characterization information;
  - Identification of remaining dismantlement activities;
  - Site remediation plans;
  - Detailed plans for final radiation survey;
  - Description of end use of site, if restricted release requested;
  - Updated estimate of remaining decommissioning costs;
  - Supplement to environmental report describing any new information or significant environmental change associated with licensee's proposed termination activities.
- Licensee must **demonstrate that applicable requirements of License Termination Rule (LTR) will be met.**

# Completion of Decommissioning

At conclusion of decommissioning activities licensee must submit  
**Final Radiation Survey Report (FRSR).** NRC will terminate license if it determines that:

- Remaining dismantlement has been performed in accordance with approved LTP;
- Final radiation survey and documentation demonstrates that facility and site are suitable for release in accordance with LT Report.



## **Terminating NRC License & Releasing Site**

- **Once public concerns are addressed, NRC terminates license if all work has followed approved LTP and final radiation survey shows that site to be suitable for release.**
- **License Termination for unrestricted use, means any residual radiation must be below NRC's limit of 25 milli-rem/year.**
- **This completes the decommissioning process.**

# **DECOMMISSIONING STRATEGY AND DECISION**



# Decommissioning Strategy

- **SAFSTOR – Advantages of Deferral:**
  - Reduced radiation, waste volume and dose level to workers
  - Allows decommissioning trust fund to increase
  - Coordinate decommissioning at several sites
  - Options for off-site disposal sites may become available
- **DECON – Advantage of Immediate Decontamination**
  - Costs and management more certain than in future
  - Knowledgeable Workforce availability immediately
  - Less likelihood of losing knowledge and expertise
  - Easier public acceptance and reclamation of site
- **Combination of SAFSTOR and DECON**
- **Transfer D&D activity, NPP license, responsibility, and direct Trust Fund payment to third-party company** experienced in full-service decommissioning: decontamination, dismantlement, demolition, removal, fuel storage and site restoration.
- **Use Multi-owner Oversight** - Joint Venture decommissioning companies to do work while NPP owner retains license and direct access to trust fund

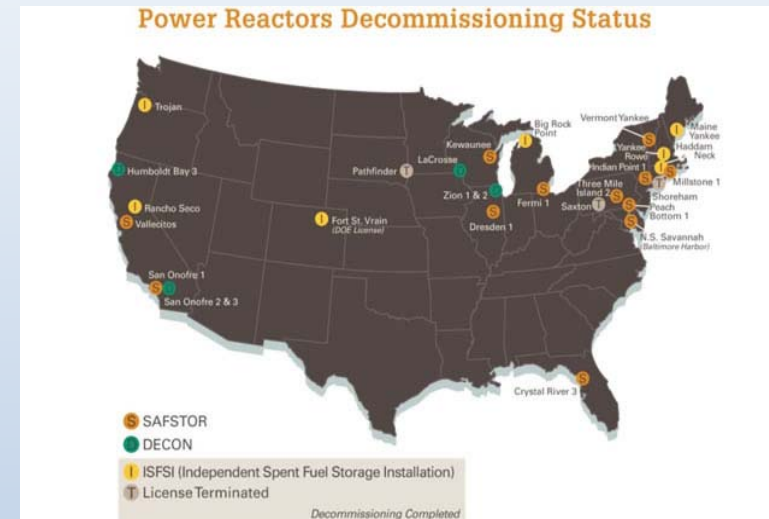
# Decision Factors in Decommissioning Strategy

- Policy Requirements and regulatory aspects
- Costs - adequate decommissioning funds
- Multiple facilities in operation
- Safety and security
- Spent Fuel and HL rad waste disposal capacity access and availability (none in U.S. currently)
- Future Site use – restricted vs unrestricted
- Social and economic impacts on community
- Stakeholders consideration– public and company desire to unburden liability
- Knowledge management – now and in future

# **Status of Decommissioning in US**

# Status of Reactor Decommissioning in U.S.

- **11 reactors completed decommissioning** safely to either license termination or to where remaining activities are limited to management of an **Independent Spent Fuel Storage Installation (ISFSI)**.
- **19 commercial reactors are in decommissioning process**
- **13 power reactors using Safestor; 16 – mostly single-unit plants – using, or have used, Decon approach**



# 11 NPPs Completed Decommissioning

Reactor	Type	Location	Ceased Operations	Fuel Onsite
Big Rock Point	BWR	Charlevoix, MI	08/29/97	YES –ISFSI ONLY
Fort St. Vrain	HTGE	Platteville, CO	08/18/89	YES –ISFSI ONLY
Connecticut Yankee	PWR	Haddam Neck, CT	12/09/96	YES – ISFSI ONLY
Maine Yankee	PWR	Wiscasset, ME	12/06/96	YES – ISFSI ONLY
Pathfinder	SH-BWR	Sioux Falls, SD	09/16/67	NO - LICENSE TERMINATED
Rancho Seco	PWR	Sacramento, CA	06/07/89	YES –ISFSI ONLY
Saxton	PWR	Saxton, PA	05/01/72	NO - LICENSE TERMINATED
Shippingport	PWR	Shippingport, PA	10/01/82	NO - LICENSE TERMINATED
Shoreham	BWR	Suffolk Co., NY	06/28/89	NO - LICENSE TERMINATED
Trojan	PWR	Portland, OR	11/09/92	YES – ISFSI+LLW STORAGE
Yankee Rowe	PWR	Franklin Co., MA	10/01/91	YES - DECON

ISFSI - independent spent fuel storage installation - a stand-alone facility within plant boundary constructed for interim storage of spent nuclear fuel. ISFSI Only means plant license has been reduced to include only the spent fuel storage facility.

# 19 U.S. Nuclear Plant Units Undergoing Decommissioning

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

<https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.pdf>

# **Dismantlement of Nuclear Power Plants**

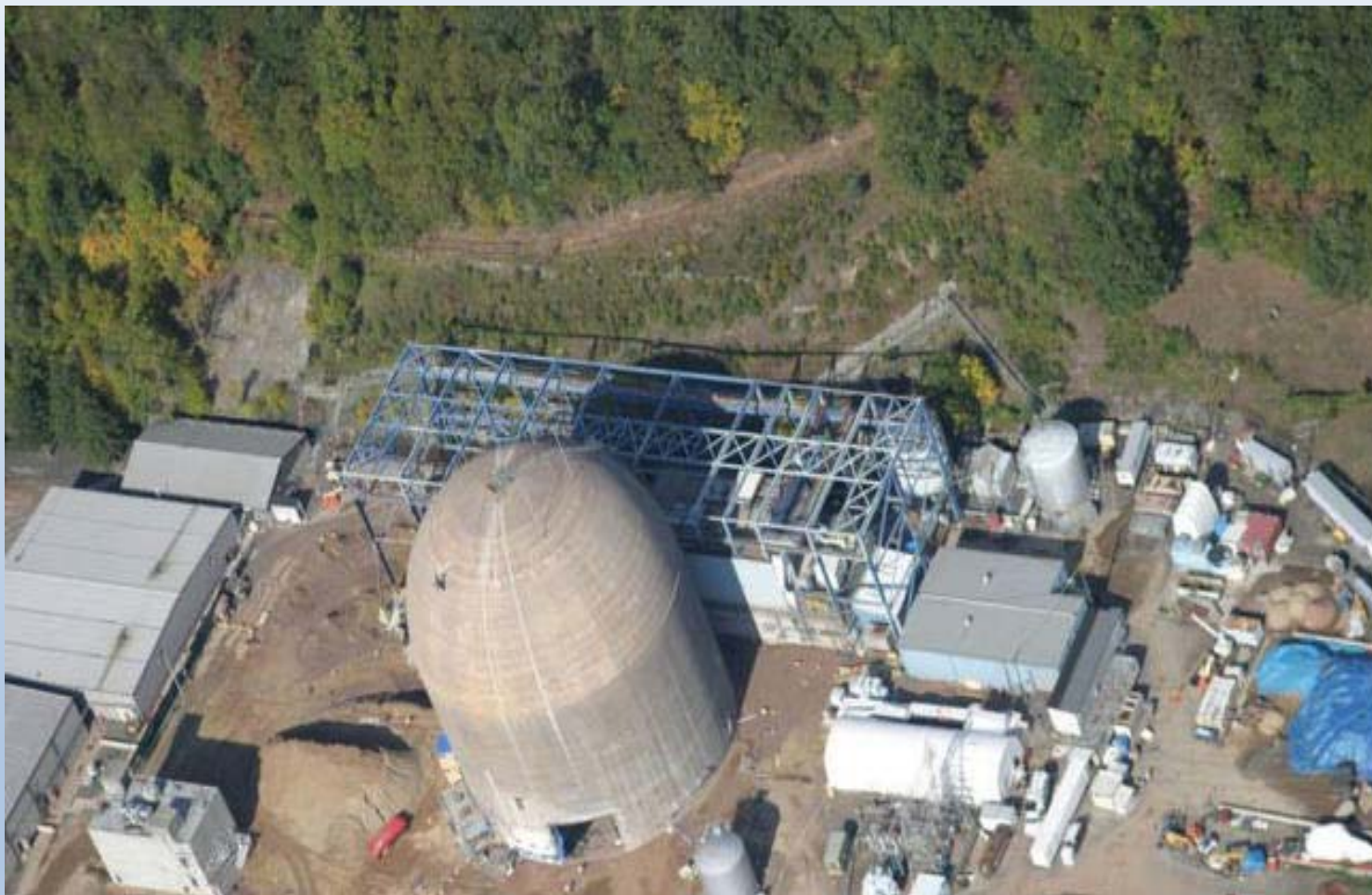
## **Case Studies in Pictures**



<https://www.youtube.com/watch?v=z7xAjxscddw>



# Dismantlement of Connecticut Yankee NPP



Courtesy of Connecticut Yankee

REF : <http://www.courant.com/business/hc-connecticut-yankee-nuclear-power-plant-pictures-photogallery.html>



# Dismantling Reactor Containment Building at Connecticut Yankee



Courtesy of Hartford Courant

<http://www.courant.com/business/hc-connecticut-yankee-nuclear-power-plant-pictures-photogallery.html>

# Removal of Encased Reactor Vessel from Connecticut Yankee NPP



**Encased in shipping container - bottom section of reactor.  
Reactor Size: 820 tons and 10.7 m height by 5.5 m- diameter**

Courtesy Hartford Courant: <http://www.courant.com/business/hc-connecticut-yankee-nuclear-power-plant-pictures-photogallery.html>



# Shipping Dismantled Reactor Vessel



**Destination: Disposal site in South Carolina**

Courtesy Hartford Courant-<http://www.courant.com/business/hc-connecticut-yankee-nuclear-power-plant-pictures-photogallery.html>

# **Transport of Two Steam Generators from Decommissioned Connecticut Yankee NPP**



**Weight of Each Steam Generators: 160 tons**

Courtesy of Hartford Courant: <http://www.courant.com/business/hc-connecticut-yankee-nuclear-power-plant-pictures-photogallery.html>



# Connecticut Yankee Nuclear Fuel Storage Facility



**Nuclear Fuel Storage Facility - storing used reactor fuel assemblies; 1.2 Km from former Connecticut Yankee NPP site**

Courtesy Hartford Courant: <http://www.courant.com/business/hc-connecticut-yankee-nuclear-power-plant-pictures-photogallery.html>

# Independent Spent Fuel Storage Installation



**Connecticut Yankee - Spent Nuclear Fuel Rod Storage in Vertical Concrete Vessels. Facility cost: \$31.6 Million (USD)**

Courtesy Hartford Courant: <http://www.courant.com/business/hc-connecticut-yankee-nuclear-power-plant-pictures-photogallery.html>



# **Maine Yankee Nuclear Plant Site Decommissioning Completed in 2007**



**Maine Yankee Before**



**Maine Yankee After**



**Demolishing Maine Yankee  
Containment Dome**

Credit: Maine Yankee

# **San Onofre Nuclear Generating Station – Unit 1 2002 - Decommissioning - Reactor Vessel Removal**

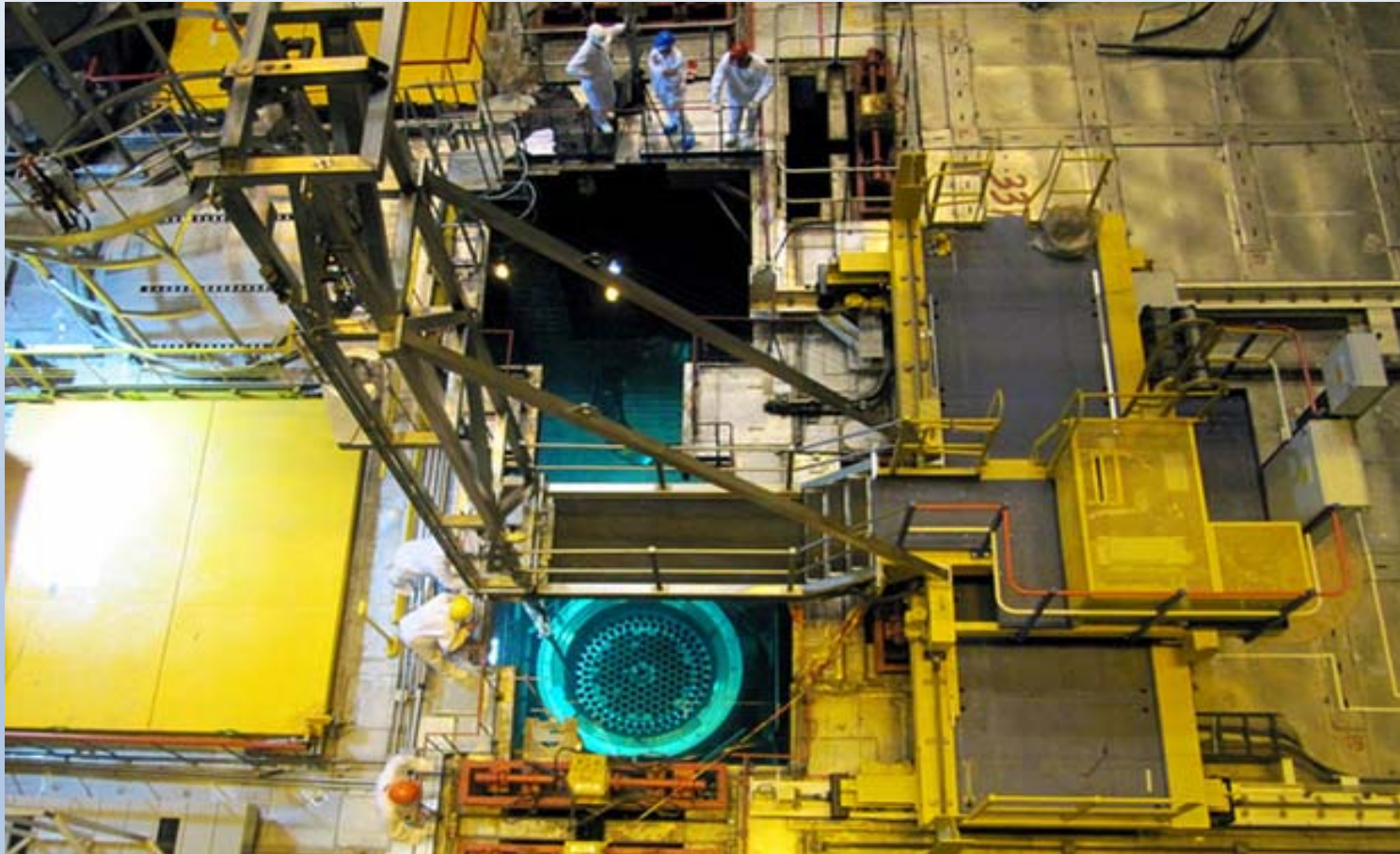


<http://cen.acs.org/articles/91/i13/Nuclear-Retirement-Anxiety.html>

Credit: Earl S. Cryer/UPI Photo Service/Newscom

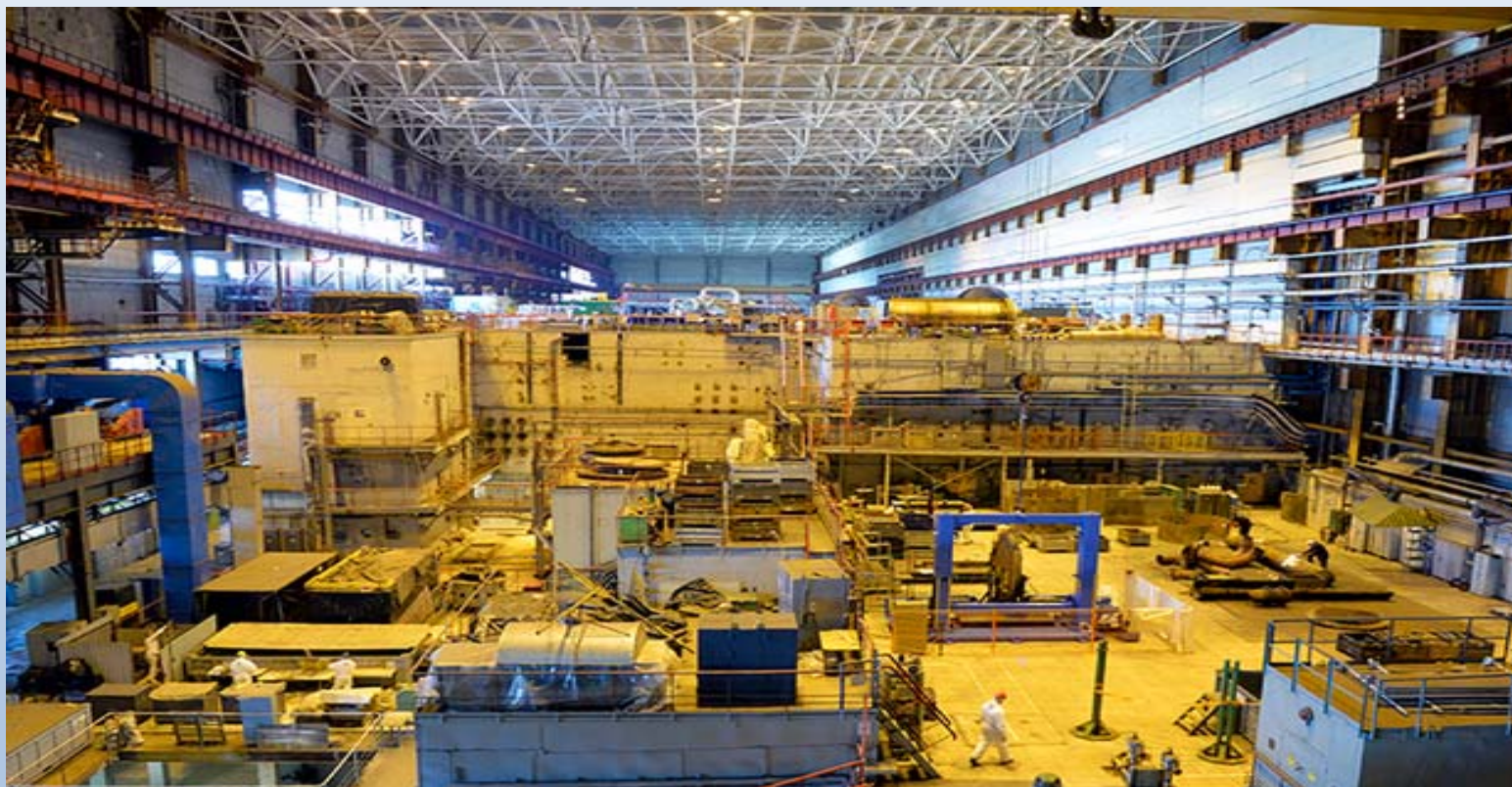


# Removing spent fuel Ignalina nuclear power plant - Lithuania



Courtesy EBRD: <http://www.ebrd.com/ignalina-photo-gallery>

# First turbine hall dismantled Ignalina NPP - Lithuania



Equipment in turbine hall 1 fully dismantled - June 2016. Dismantled contaminated equipment further treated for subsequent storage safely in waste management facilities

Courtesy EBRD: <http://www.ebrd.com/ignalina-photo-gallery>



# Swedish NPP Decommissioning and Conversion – Contaminated Surfaces Removal



All surfaces in contact with water in the reactor are contaminated to some extent with radioactivity  
Ringshal NPP.

# Swedish NPP Decommissioning and Conversion



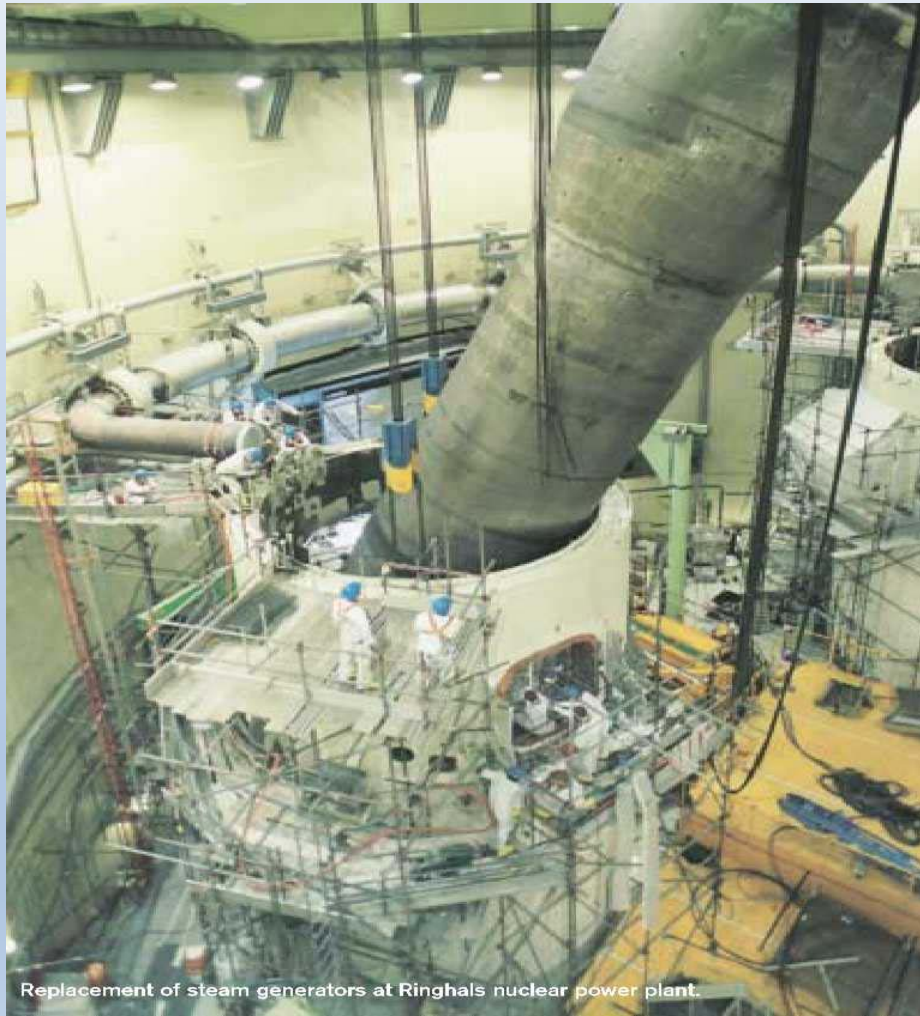
Contaminated areas are drilled away and disposed



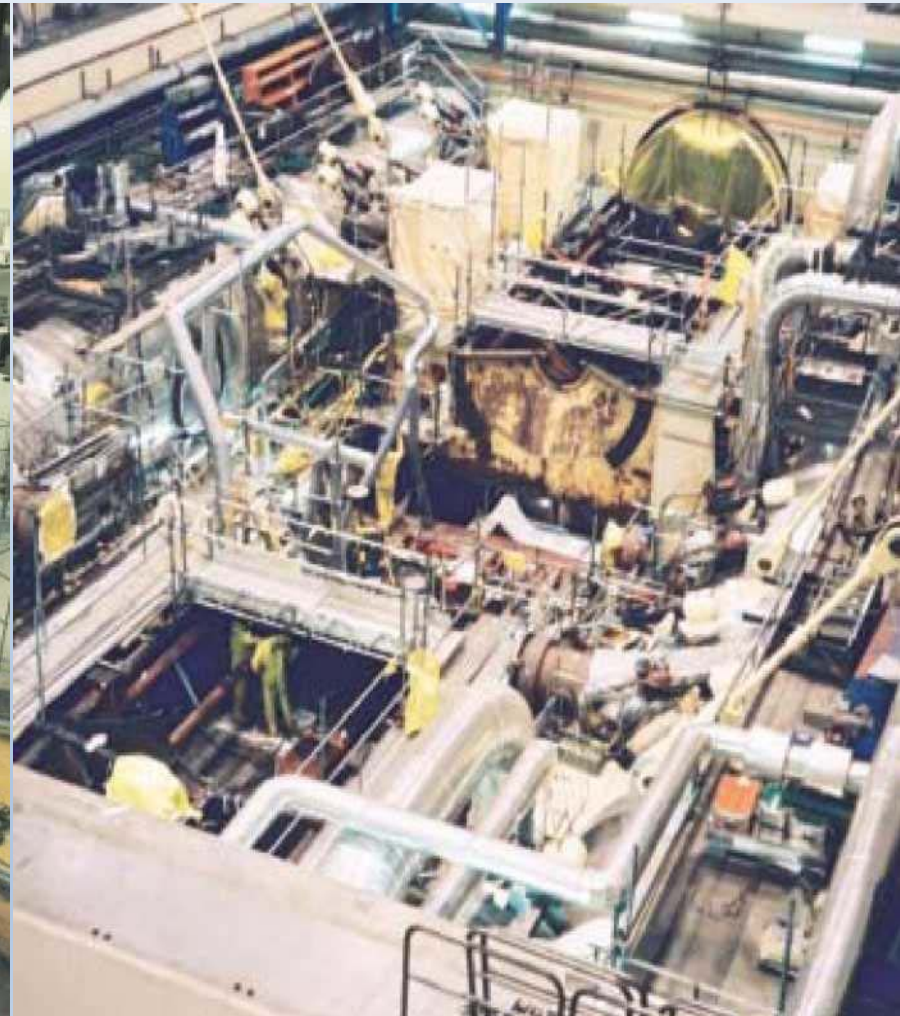
Personnel and equipment must suffice for the decommissioning of all Swedish nuclear power plants.



# Swedish NPP Decommissioning and Re-use Conversion – Steam Generator and Turbine Replacement



Replacement of steam generators at Ringhals nuclear power plant.



Turbine replacement at Oskarshamn nuclear power plant.

[http://www.skb.se/publikation/1043658/RIVNING\\_ENG.pdf](http://www.skb.se/publikation/1043658/RIVNING_ENG.pdf)

# Challenges and Issues in Decommissioning

- **Removal of on-site spent fuel and waste storage** to repository or interim storage
- **Sufficiency of funds** to cover costs – legacy costs to future rate payers
- **SAFSTOR – U.S. allows up to 60 years to complete** decommissioning– raises issues: ties up site; **can trust fund cover future costs; future accountability** of responsibility if entity no longer in business; available **future expertise**; **public reaction to existing site**
- **Third party (LLC) assignment of license** for decommissioning – completion and cost risks
- **Maintaining site use options for future**
- **Incorporating D&D into new NPP design**



**Connecticut Yankee - Spent Nuclear Fuel Rod Storage**

# **DECOMMISSIONING FUNDING AND COSTS**

# Decommissioning Trust Funds

- **Planning for decommissioning starts as soon as facility begins operation.** All NPPs must comply with NRC's decommissioning funding regulations
- **NRC requires licensees to submit decommissioning funding estimates every two years during operation for review of funding status and adequacy.**
- **Licensees - set aside \$53 billion for decommissioning**
- **Decommissioning trust funds are not under direct administrative control of the generating companies**
- **Use of funds limited to legitimate decommissioning expenses.**

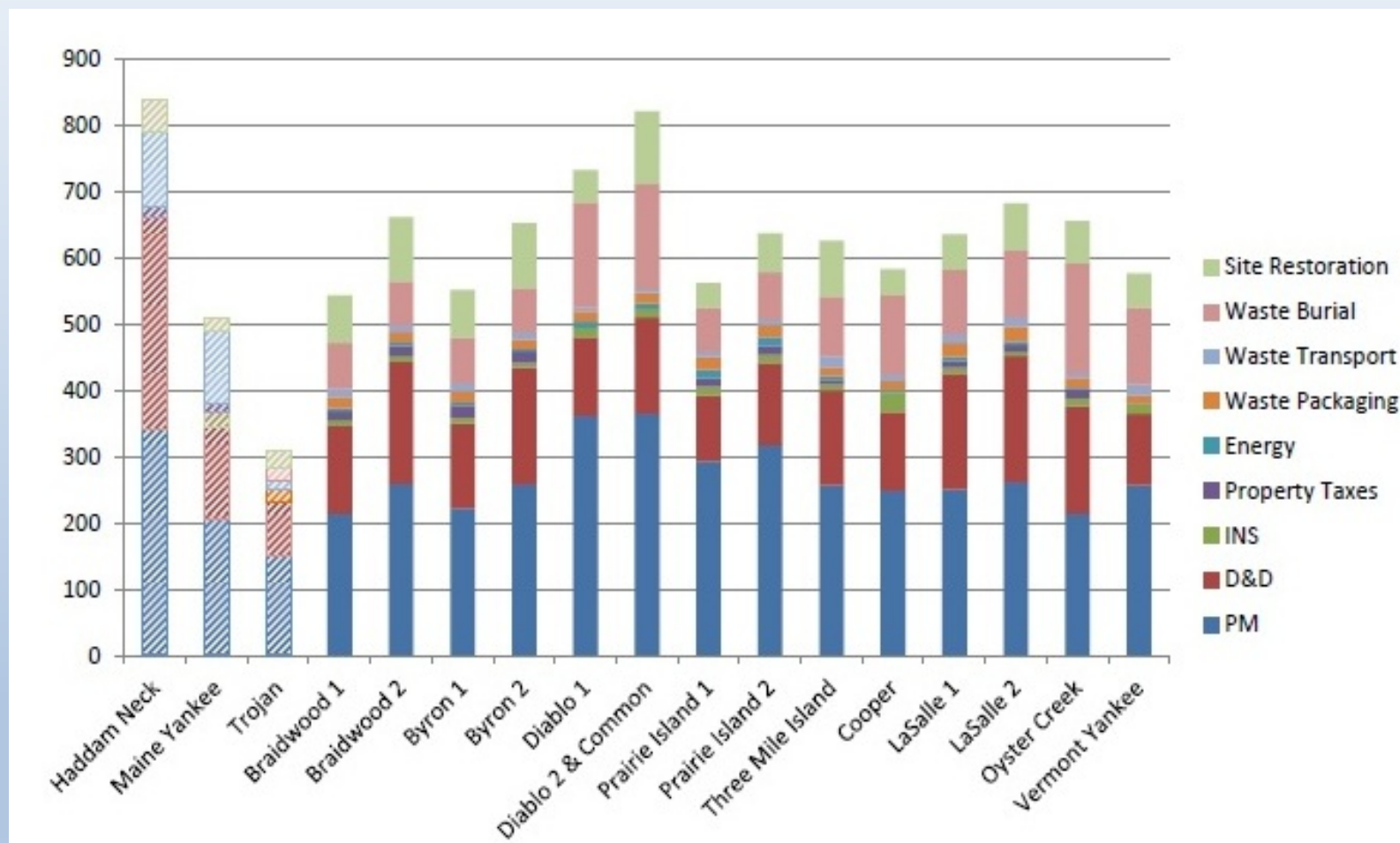


# Funding and Estimates of Decommissioning Costs

- In US, nuclear utilities collecting 0.1 to 0.2 cents/kWh to fund decommissioning. Must report to NRC on status every 2 years.
- **OECD- NEA survey (2016) reported costs in \$USD (2013)**
  - **US reactors** - expected total costs range \$544 M to \$821 M
  - **For units >1100 Mwe**, costs ranged from \$0.46M to \$0.73 M/Mwe; **for units half that size**, costs ranged from \$1.07M to \$1.22 M/MWe.
  - **Finland's Loviisa (2 x 502 MWe)** - estimated at €326 M.
  - **A Swiss 1000 MWe PWR-** estimated CHF 663 M (€617 M).
  - **In Slovakia, detailed study showed** cost to decommission Bohunice V1 (2 x 440 MWe) at €1.14 B with dismantlement by 2025.

# Costs in \$M (2013) for U.S. NPPs Undergoing Decommissioning

Costs in \$M (USD - 2013)



Source: NEA's 'Costs of Decommissioning Power Plants' report (2016).

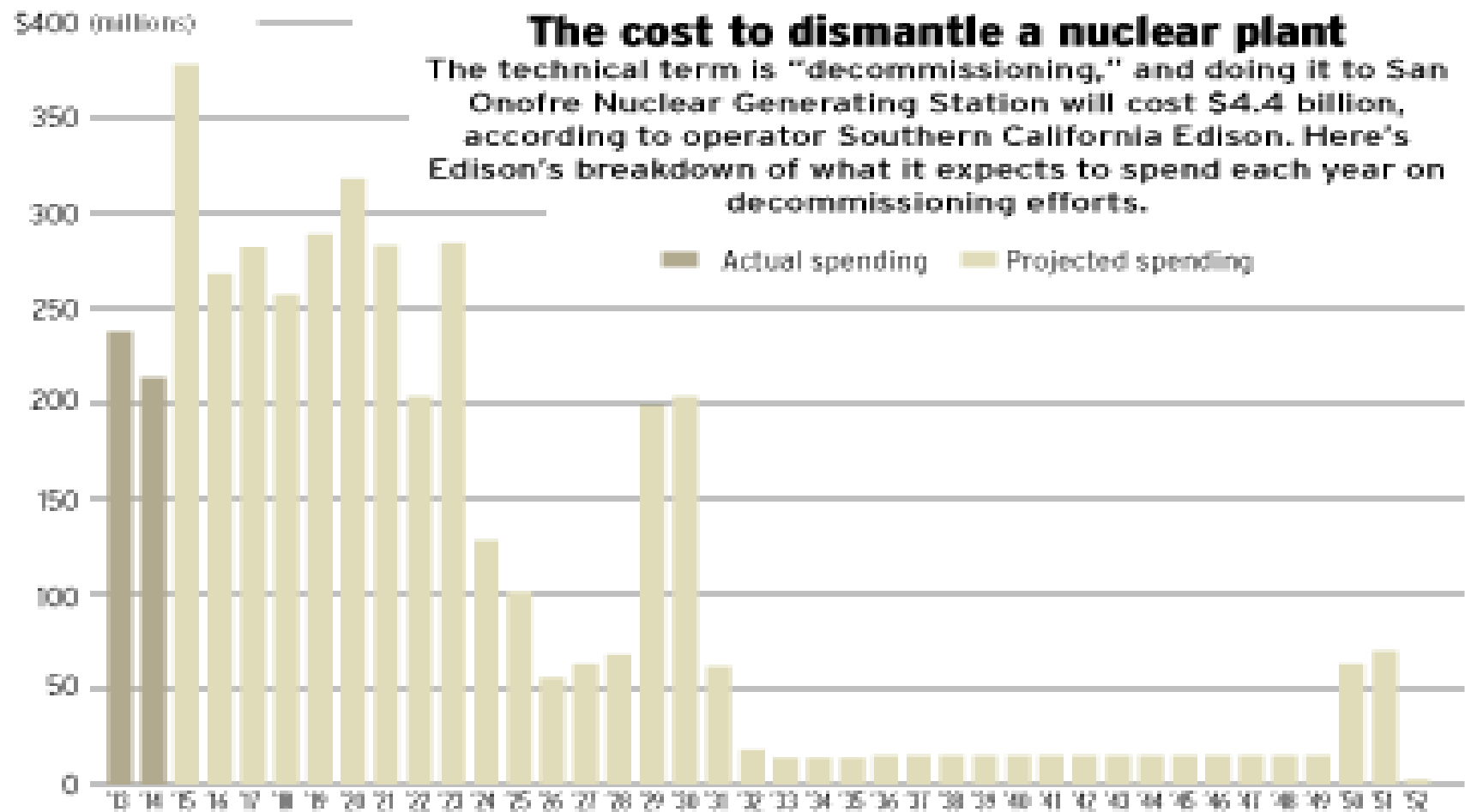
<http://analysis.nuclearenergyinsider.com/us-operators-urged-decommission-immediately-prevent-cost-hikes>

## Examples of Decommissioning Costs of Nuclear Plants in US

- **Diablo Canyon Units 1 & 2**, California estimated at > \$2.1 B
- **Haddam Neck (Connecticut Yankee plant)**, Connecticut - dismantled in 1996 cost at \$1.2 Billion (cost overrun from original estimate \$719M)
- **Maine Yankee**, Maine (860MWe) – completed decommissioning in 2005 after 8 years, at cost of over \$500M
- **Yankee Rowe** – completed decommissioning in 2007 - \$608M
- **Clinton nuclear plant**, Illinois – decommissioning cost estimated \$960 million (\$USD); license termination of 2036
- **Calvert Cliff's Units 1 & 2**, Maryland – estimated costs of each at \$668 M, License Termination in 2024 and 2026 respectively
- **Trojan** (1180 MWe, PWR), Oregon the dismantling was undertaken by the utility itself in – released for unrestricted use – 2006- \$300M.

# Cost Estimates Are Higher than Original Plan

## Spending Profile- San Onofre Nuclear Generation Station – 2 Units



Sources: Southern California Edison and Public Utilities Commission

STAFF GRAPHIC

# **Implications for Republic of Korea Nuclear Decommissioning Decisions on first NPP**

- **Strong management and clear lines of responsibility for decisions are critical to success**
- **Decommission Option: contract out or utility-owner to do?**
- **DECON vs SAFSTOR decision – will public accept long waiting period under SAFSTOR?**
- **Assess similarities and variations in regulatory process for decommissioning (US, ROK – and IAEA) – for safety**
- **Assurance of adequate funding and realistic cost and schedule estimates (inflation and contingency) is essential**
- **Continuation of on-site storage – Independent Spent Fuel Storage Installation (ISFSI) – how long and at what cost?**
- **Constraints at sites for NPP decommissioning:**
  - **Coordination of logistics with operating NPPs at site;**
  - **Site space and infrastructure constraints if want new NPP**
  - **Timing & options for re-use - Nuclear and Non-nuclear**

# **Areas of Potential R&D Collaboration and Knowledge Sharing**

- **Test cost estimation methodologies against actual decommissioning costs for recent NPPs and identify high cost-risk areas**
- **Best practices for effective and efficient decommissioning strategies, plans, management, and processes, including public engagement and TRUST**
- **Case studies of decommissioned PWR's in U.S., EU with Korea PWR strategy.**
- **Assess implications of differences in U.S. and Korea decommissioning and decontamination regulations, standards and guidance and basis/rationale and influence on estimated costs**
- **Modeling and scenario analyses to assess risks in decommissioning**
- **Research on advanced robotics technology for complex tasks in high radioactive areas for DECON**
- **Analyze options of facilities re-use and infrastructure assets of NPP targeted for decommissioning located at sites with operating NPPs**
- **Waste management, storage and repository for SNF and RW design and strategies**

# Closing Remarks

- **As the first NPP in Korea to be decommissioned, important to do everything right and transparently in the public's view.**
- **Much can be learned from prior experiences & processes in decommissioned NPPs that can inform Korea's decommissioning strategy, enhance safety, and reduce costs**
- **Engage expert advisors to review contracts and Work Breakdown Structure (WBS) for decommissioning**
- **Assurance of funds availability; accurate cost estimates and WBS are important to successful Decontamination & Decommissioning**
- **Public engagement and TRUST- a key consideration**
- **Solutions needed for permanent off-site storage or disposal beyond temporary onsite storage spent fuel and radioactive waste**