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WASTE MANAGEMENT FOR DECOMMISSIONING OF NUCLEAR POWER PLANTS: AN EPRI DECOMMISSIONING PROGRAM REPORT

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ABSTRACT

The Electric Power Research Institute (EPRI) is a non-profit research organization that conducts research related to the generation, delivery, use, and environmental impacts of electricity. EPRI also conducts research for the safe and optimized decommissioning of nuclear power plants through its Decommissioning and Remediation Technology Program.

The decommissioning of a nuclear power plant involves the safe disposition of a large quantity of radioactive, hazardous and conventional waste. The logistics of characterizing, staging, packaging and shipment of this waste needs to be carefully planned so as to support the decommissioning project schedule. The most efficient decommissioning and waste management process is one in which effective waste management and disposal options are available as the waste is being generated so as not to delay or impede the progress of decommissioning.

As the cost of waste disposal is a large component of the total decommissioning budget, the optimal treatment and disposal option needs to be chosen for each type of waste. Waste must be generated, classified, and segregated in such as manner as to take advantage of all available disposal pathways: clearance, very low level waste, non-radioactive/hazardous waste, and low level waste disposal sites. This approach will help to avoid the unnecessary use of scarce disposal capacity needed for the higher activity waste.

There has been a number of nuclear power plant decommissioning projects successfully completed in the United States. These projects have used various waste disposal options and developed successful methods for handling the large quantities of waste created by the decommissioning. Additionally, decommissioning projects in Europe are in progress or in the planning stages such that strategies for the handling of decommissioning waste are being developed and/or implemented to address the regulatory requirements and disposal options available in these countries.

EPRI is preparing a report to be issued in 2014 on decommissioning waste management experiences that will provide summaries of:

- Waste management experiences in the United States during power plant decommissioning projects.
- Waste management plans and experiences for some of the decommissioning projects in other countries that are in progress where these plans have been developed or are being implemented.

In line with the subject of this symposium, this paper will focus on the disposition of metal waste from decommissioning including the following:

- The overall radioactive waste management experiences in the U.S. compared to the waste situation in other countries, particularly in Europe, where relatively high waste disposal costs and established clearance levels have resulted in the development of processing methods to reduce the volume of radioactive waste requiring disposal.
- Metal recycle experiences in the U.S where disposal costs are relatively low and large components can often be disposed of in one piece in shallow land burial. These factors and lack of clearance levels have limited the cost benefit of metal recycle in the United States.

BACKGROUND

The US Nuclear Regulatory Commission defines the classification of radioactive waste in Title 10 of the Code of Federal Regulations Part 61.55. The waste classes (A, B, C and GTCC) correspond to increasing radionuclide concentrations and protective requirements for disposal that are defined in this regulation as follows:

- Class A waste with minimal requirements,
- Class B waste requires more rigorous requirements for waste stability,
- Class C waste also requires stability and additional intruder protection measures,
- Greater than Class C (GTCC) waste is not acceptable for near-surface disposal and requires disposal in a geologic repository.

Waste Disposal Options

There are a limited number of disposal options for low level radioactive waste in the U.S. after the closure of the Barnwell, South Carolina site to all waste except that from the states of Connecticut, New Jersey and South Carolina in 2008. The following are the primary waste disposal options available to the power plant licensees in the US in the approximate order from the most often used to the least used by US decommissioning sites.

- **EnergySolutions - Clive, Utah site**

  The Clive, Utah site receives most of the low level waste currently generated in the US as it can accept waste from any state. The site is licensed by the NRC and the State of Utah to receive only Class A waste. Current standard waste costs for Class A waste at EnergySolutions are in the range of 2,600 Euros/m^3.

- **State Licensed Landfills (No NRC License Required)**

  - **Tennessee Licensed Landfills**

    There are a few of hazardous/radioactive waste landfills licensed by the State of Tennessee. These landfills can receive waste with radioactivity levels up to an approximate range of 0.5 Bq/g of gamma radionuclides through their Bulk Survey For Release (BSFR) program. Approximate disposal cost at these sites is 1,100 Euro/m^3.

  - **US Ecology Idaho Facility**

    The US Ecology Idaho facility is licensed by the State of Idaho and can receive hazardous waste. It can also receive waste that has been exempted by the US NRC after special approval under 10 CFR 20.2002. Waste with gamma activity levels of approximately 0.6 Bq/g has been exempted for disposal this facility. Disposal cost at this site for NRC exempted waste is typically below 550 Euro/ m^3.

- **Waste Control Specialists – Andrews, Texas Site**

  The Andrews, Texas site is licensed by the NRC and the State of Texas to receive Class A, B and C waste from Texas and Vermont (the Texas Compact). The State of Texas also recently authorized disposal of a limited quantity of waste from other states through an application and approval process administrated by the State of Texas. This development presents the only disposal option for Class B and Class C waste for most of the power plant licensees in the U.S. Class B/C disposal costs for "out of compact" licensees at the Andrews site are in the range of 133,000 Euro/m^3.

Typical Decommissioning Waste Volumes

Table 1 compares the volume of radioactive waste expected to be generated during the decommissioning of a typical power plant in Europe to that from selected decommissioning projects in the US. It is logical that the expected volume of waste from the decommissioning of a European plant is considerably less than US plants as much of the waste that would be classified as Low Level Waste in the U.S. would meet the clearance criteria in Europe and be disposed of as conventional waste. Also, due to higher waste disposal costs in Europe, much more waste is decontaminated to clearance levels compared to the U.S. where decontamination to "Free Release" (i.e., not detectable activity) levels is typically not cost beneficial.

Table 1
Decommissioning Radioactive Waste Volume Estimates and Actuals for U.S. Power Plants

Waste Type (U.S. Classification)	Estimate for Selected European Plants (m^3)	Maine Yankee - US (860 MWe-PWR) (m^3)	Rancho Seco - US (913 MWe-PWR) (m^3)
Very Low Level and Low Level (Class A)	2,911	90,650	17,244
Intermediate Level (Class B and C)	2,459	570	93
Greater Than Intermediate Level (GTCC)	109	Not Available	11
Total	5,479	106,610	17,348
Decommissioning Strategy	Decontaminate Buildings and Equipment to Clearance Levels	Little Decontamination of Buildings and Equipment	Decontamination of Buildings, Little Decontamination of Equipment

As can be seen from Table 1, most of radioactive waste from power plant decommissionings in the U.S. is low activity, Class A waste. This type of waste from decommissionings is typically shipped in bulk form (as shown in Figure 1 for the Maine Yankee Plant) and disposed of unpackaged at sites like the EnergySolutions facility in Clive, Utah.

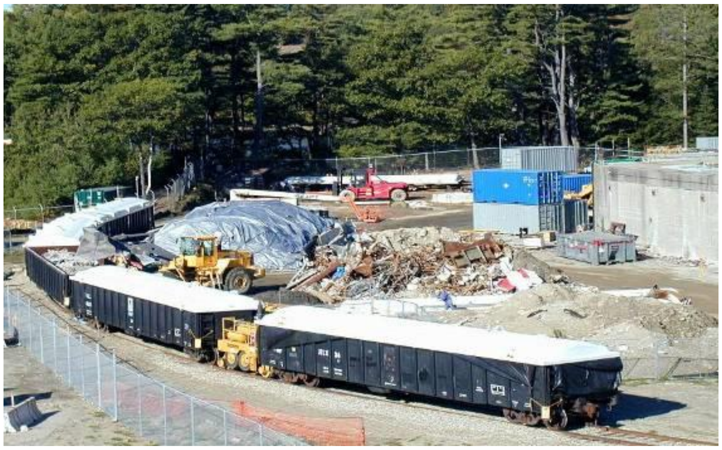

Figure 1
Bulk Radioactive Waste Shipment (Maine Yankee)

U.S. Large Component Shipping and Disposal Experiences

The power plant licensees have successfully proposed to the US NRC that the robust construction of most large components make them a suitable shipping package that does not require the qualification testing required for other packaging for this category of waste. Large components such as Reactor Vessels and Steam Generators (S/Gs) can be:

- Qualified for shipping in one piece
- Disposed at U.S. shallow land disposal facilities with little or no segmentation (other than removal of the GTCC Reactor Internals)

Note that U.S. regulations allow the component activity to be averaged over the entire weight of the large component. This has allowed some S/G Lower Assemblies to qualify as Class A waste for disposal at Clive, Utah.

Figures 2 and 3 show the shipment of the reactor vessel from the Connecticut Yankee (CY) plant by barge to the Barnwell, South Carolina waste disposal site (Maine Yankee reactor vessel can also be seen in Figure 3).

Figure 2
Shipment of the Connecticut Yankee (CY) Reactor Vessel

Figure 3
Disposal of CY Reactor Vessel at Barnwell, SC

Special Consideration for Steam Generator (S/G) Removal, Shipment and Disposal

The removal of the steam generators has not been overly challenging as removals and in some cases replacements had been successfully accomplished at a number of other nuclear power plants. Due to the ability to dispose of S/Gs in one or two pieces, typical disposition options for a S/G in the U.S. are:

- Option 1: Dispose of in one piece if small enough to ship to disposal site
- Option 2: Separate the Steam Dome from Lower Assembly

As an example, for the S/Gs at CY, the upper portion of the steam generators (called the Steam Dome) was separated from the lower portion in place inside the containment building with a horizontal cut, the open end sealed with a welded metal plate and shipped to the EnergySolutions disposal site in Clive, Utah by rail. The lower portion of the steam generator, containing the channel head and tube bundle, exceeded the Class A disposal limits and therefore needed to be disposed of in the Barnwell, South Carolina disposal site. Both segments were qualified to meet shipping and disposal package limits by sealing all vessel penetrations.

Figures 4 thru 6 show a CY Steam Generator segmented, packaged and various steps of the shipment to the disposal site.

Figure 4
Removal of CY S/G Lower Assembly from the Containment Building

Figure 5
CY S/G Dome Lower on Transporter for Movement to Rail Spur

Figure 6
Moving S/G Lower Assembly (with Shielding) to Barge Slip and Via Rail in South Carolina

The approach like that used by Connecticut Yankee for the S/Gs:

- Facilitates shipment to disposal site in two pieces ***and***
- Allows the Steam Dome to be segmented and disposed of at a lower overall cost

The result of the ability to dispose of large components in one or a few pieces and the relatively low disposal costs in the U.S. have made the decontamination and/or complete segmentation of S/Gs (and other large components) in the U.S. typically not a cost effective option.

Decommissioning Waste Management Lesson Learned

One major lessoned learned during decommissioning in the U.S. is that there are typically a number of tasks that are occurring simultaneously. Figure 7 shows this situation during San Onofre Unit 1 decommissioning.

Figure 7
Concurrent Activities during the San Onofre Unit 1 Decommissioning

This illustrates that a comprehensive Waste Management Plan is needed during a power plant decommissioning. This plan should:

- Define appropriate waste disposal methods
- Determine the decontamination vs. disposal strategy considering waste disposal costs
- Select options for packaging and transport
- Plan the on-site routing of wastes
- Consider how the decommissioning project sequence will affect waste management
- Consider how decommissioning waste often is created faster than it can be shipped, large staging areas may be needed

METAL RECYCLE IN THE UNITED STATES

There are no clearance levels for metal waste from power plants in the United States. Waste to be unconditionally released from radiological control (for general use or to a recycler) must be shown to contain “no detectable radioactivity” in conformance with US NRC guidance. The unconditional release survey of metals must be conducted as follows:

- Using a survey instrument with a minimum sensitivity of 0.83 Bq/cm^2 (Beta/Gamma Activity)
- Perform a final aggregate survey of the waste (Typically performed as the truck exits the site using a gamma sensitive Truck Monitor)

These surface contamination surveys of metals to be released are typically performed by:

- Health Physics Technicians at Power Plant Sites
- At a centralized processing facility such the EnergySolutions facilities in Memphis and Oak Ridge, Tennessee

Metals with Recycle Potential

There are a number of types of metals that have the potential for cost effective recycle. Some of these and their potential uses are:

- Lead (Shielding, Waste Packages)
- Nickel (Steam Generator Tubing)
- Steel (Carbon and Stainless)
  - Shielding
  - Radioactive Waste Packages
- Metals with PCB Paint >50 ppm (i.e., released painted metal from Connecticut Yankee was sent to a recycler avoiding a special hazardous material disposal cost)

It should be noted that neutron activated metals are generally not candidates for recycle as the contamination is volumetric and not restricted to the surface of the metal.

Decontamination Prior to Recycle

Decontamination to unconditional release levels can be a useful precursor to recycling. Some of the general techniques are:

- Performed in decontamination enclosures
  - Water Wash (Hot and Cold)
  - Grit Blast (Typically not effective for convoluted surfaces and lead)
  - Dry Ice Blasting
- Chemical Decontamination (i.e., EPRI DfD and DfDX Processes)
- Wiping
- Planing (i.e., Mechanical Removal of Surface Layer of Lead)

An important factor in the cost evaluation of metal decontamination is to minimize of the creation of secondary waste during the decontamination. Figure 8 show processing skids which employ the EPRI DfDX chemical decontamination process.

Figure 8
EPRI DfDX Equipment Skids

Figure 9 shows a Boiling Water Reactor Heat Exchanger Bundle that has be decontaminated with the EPRI DfD process and unconditionally released.

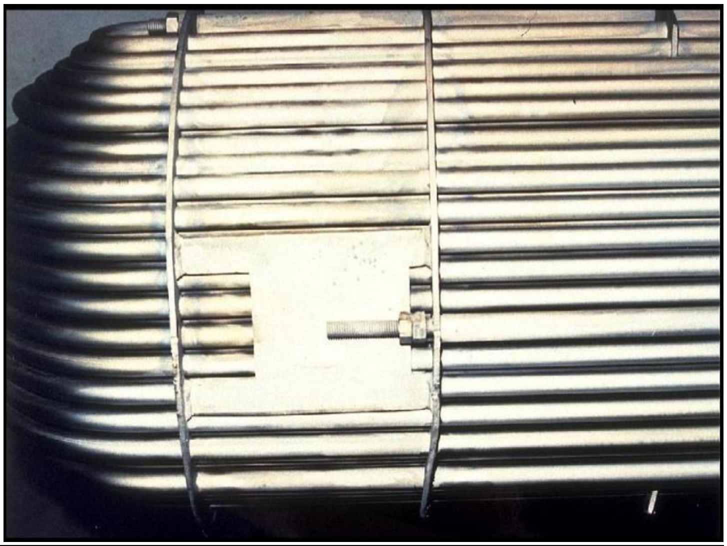

Figure 9
BWR Heat Exchanger Bundle after Decontamination with EPRI DfD

Metal Melting Prior to Recycle

The melting of metal in a foundry-like process has been used in a number of countries as part of the recycling of slightly contaminated metals. During the melting process, non-metal radionuclides, such as Cesium and Plutonium, rise to the surface of the melt and can be removed from the remainder of the melt as slag. Metal radionuclides, such as Cobalt and Nickel stay in the melt. At the peak of the recycling of metal released from radiological control areas in the U.S. in 1995, 13,600 tones/yr of carbon and stainless steel was recycled to general industry. This yearly volume amounted to less than 1 percent of the total radioactive scrap inventory in the U.S. in 1999.

The public was concerned that some radioactivity remained in this released metal that was being recycled into commercial products. In 2000, the US Department of Energy (DOE) suspended the unrestricted release of all scrap metal from radiological control areas at their facilities.

Metal Recycle into Uses in the Nuclear Industry

In the U.S., the DOE, power plant and other radioactive material license holders have used metal melting to reuse slightly contaminated scrap metal that met predetermined limits through a "controlled" release process. This metal was subsequently used in radiologically "controlled" nuclear industry locations. The DOE has been particularly successful in the recycling of slightly contaminated scrap metal. Some statistics of the DOE's recycle program:

- Recycle of lead:
    - As of 2004, the DOE had recycled 710 tones of lead at a savings of approximately 2.5 million Euros
    - Lead Used:
        - Shielding Products
        - Shipping Casks
- Recycle of other metals into Radwaste drums and security barriers

Saving result through this process as:

- U.S. disposal costs for Lead in 2004 was 6 Euros/kg (Encapsulation in plastic required)
- Recycling costs are approximately 3 Euros/kg

Figures 10 and 11 show some of the products fabricated out of recycled slightly contaminated lead.

Figure 10
Recycled Lead Used by NASA

Figure 11
Shielded Shipping Container

EnergySolution Oak Ridge Tennessee Facility

EnergySolutions has processing capabilities for various types of radioactive waste at its' Bear Creek facility located in Oak Ridge, Tennessee. These processes include:

- Incineration of solids, liquids, oils and sludges
- High Force Compaction

- Melting of lead and scrap metal

As the decommissioning of a nuclear power plant results in a large amount of slightly contaminated lead and metal, the last bullet presents a possible disposition for this material.

The has been a need for shield blocks for high energy test facilities and other uses in the nuclear industry such as waste containers, security barriers and shipping casks (which can also utilize contaminated lead). These recycle uses provide a disposition pathway for slightly contaminated lead and scrap metal that does not meet the free release criteria in the U.S.. From 1994 to 2007, 54 million kgs of metal has been process for recycle by Energy Solutions. Figure 12 shows the metal melter and resulting shield block at the Bear Creek facility.

Figure 12
EnergySolutions Metal Melter and Shield Blocks for Recycle

Potential for Recycle of Nickel

The recycle of nickel presents a potentially cost effective process that also reduces radwaste volume. Nickel has a fairly high value of approximately 10,000 Euros per ton. Inventories of highly pure (low elemental Cobalt content) Nickel have existed including significant quantities at DOE facilities being decommissioned. Each new PWR Steam Generator requires approximately 75 tones of Nickel for the Inconel 690 used for the tubing.

The process that could be used to carry out this recycle would be:

- Decontaminate the contaminated Nickel
- Melt with appropriate alloying constituents to form Alloy 690

This process has not been done to date in the U.S. for non-technical reasons.

SUMMARY

To summarize the major points of this paper, in the U.S.:

- There are no clearance levels
- Due to low disposal costs, contaminated metal is not usually recycled
- Decontamination is the primary metal volume reduction method
- Where reuse in a controlled "nuclear" application is available, cost savings have been substantial

A new EPRI report to be published in 2014*, "Waste Management for Decommissioning"*, will discuss all aspects of Decommissioning Waste Management.

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